REGIONALIZATION OF LOW FLOW CHARACTERISTICS

NORTHEASTERN AND NORTHWESTERN ONTARIO

AUGUST 1995

Ontario

Ministry of
Environment
and Energy

ISBN 0-7778-2195-8

REGIONALIZATION OF

LOW FLOW CHARACTERISTICS

NORTHEASTERN AND NORTHWESTERN ONTARIO

AUGUST 1995

Cette publication technique
n'est disponible qu'en anglais.

PIBS 2553E

REGIONALIZATION OF

LOW FLOW CHARACTERISTICS

NORTHEASTERN AND NORTHWESTERN ONTARIO

Report prepared by:

Cumming Cockburn Limited
300 - 65 Allstate Parkway
Unionville, Ontario L3R 9X1
July, 1993

Report prepared for:

Ontario Ministry of Environment and Energy

7354

July 21, 1993

Ministry of the Environment and Energy
40 St. Clair Ave. West
11th Floor
Toronto, Ontario
M4V 1M2

Attention: Dr. Lloyd A. Logan, P. Eng., Coordinator
Hydrology and Networks Unit, Water Resources Branch

Dear Sir:

Re: Regionalization of Low Flow Characteristics
Northeastern and Northwestern Ontario

Please find enclosed our final report on this study, incorporating your review and comments on the previous versions.

Thank you for the opportunity to undertake these challenging and interesting investigations.

Yours very truly,

CUMMING COCKBURN LIMITED

H. S. Belore, P. Eng.
Project Manager
Director of Resources Group

HSB:ty

DISCLAIMER

This report was prepared for the Ontario Ministry of Environment and Energy as part of a ministry-funded project. The views and ideas expressed in this report are those of the authors and do not reflect the policies of the Ministry, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ACKNOWLEDGEMENTS

The following professionals, support staff and review personnel provided input and assistance throughout these investigations:

Dr. Lloyd Logan	Ministry of the Environment and Energy
Mr. Harold Belore	Cumming Cockburn Limited
Mr. Dave Ashfield	Cumming Cockburn Limited
Mr. Ross Zhou	Cumming Cockburn Limited
Mr. Sundaram Indrarajah	Cumming Cockburn Limited
Mr. Perry Pearlston	Cumming Cockburn Limited

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN REGIONS OF ONTARIO

TABLE OF CONTENTS

TABLE OF CONTENTS continued

LIST OF APPENDICES

LIST OF TABLES

LIST OF TABLES continued

(following page #)

LIST OF TABLES continued

LIST OF FIGURES

LIST OF FIGURES continued

(following page #)

LIST OF SYMBOLS

Symbols		Definition
a	-	The shape parameter of Weibull III distribution
ACLS	-	Area controlled by lakes and swamps
A_0 A_1, A_1^1, A_1^2 A_2, A_2^1 A_3, A_3^1	-	Parameter estimates obtained from the use of multi-variate regression procedures
BFI	-	Base flow index
C.V.	-	Coefficient of variation
DA	-	Watershed area
D.F.	-	Degrees of freedom

LIST OF SYMBOLS continued

e	-	The lower boundary parameter of Weibull III distribution
E(S)	-	Mean value of S
EVA	-	Mean annual evaporation
F(X)	-	Probability of nonexceedence of X
H	-	Heterogeneity measure
Lat	-	Latitude
$L - C_k$	-	The coefficient of Kurtosis by L-moments
$L - C_s$	-	The coefficient of skewness by L-moments
$L - C_v$	-	The coefficient of variation by L-moments
L - Moments	-	Linear probability weighted moments
Ln	-	Natural logarithm
LNTH	-	Stream length
Long	-	Longitude
MAP	-	Mean annual precipitation
MAR	-	Mean annual runoff
MAS	-	Mean annual snowfall
n Qmax	-	Maximum n days low flow
n Qmean	-	Mean n days low flow
n Qmin	-	Minimum n days low flow
n Qy	-	n days low flow with y years recurrence interval
N_1, N_2	-	Run numbers of the run test for randomness
$N.S.R.^2$	-	Nash - Sutcliffe measure of model efficiency
Q_m	-	Mean discharge of the test stations
Qmean, Lambda 1	-	Mean flow
Q_o	-	Observed discharge
Q_s	-	Simulated discharge
R^2	-	Coefficient of simple determination
RLWRS	-	Robust locally weighted regression smooth
RN, REG	-	Regulation code
S	-	mann-Kendall statistic
S.D. Lambda 2	-	Standard deviation
SF1	-	Shape factor 1 defined by $DA/LNTH^2$
SF2	-	Shape factor 2 defined by DA/LNTH
Sgn	-	Sign function
S.T.	-	Studentized Coefficient
T.I.	-	Trend Indicator

LIST OF SYMBOLS continued

T.L.	-	Test Limit
U	-	The characteristic drought of Weibull III distribution
V	-	Weighted L-moment standard deviation
Var (S)	-	Variance of S
y	-	Recurrence period
Z_m	-	Mann-Kendall variable
ε	-	Error in sensitivity analysis testing
ϕ (x)	-	Probability density function
ρ	-	Spearman statistic
τ	-	Mann-Kendall tau for trend test

1.0 INTRODUCTION

1.1 General

The knowledge of hydrologic low flow characteristics can be of primary importance for input to the watershed management decision making process. For example, when analysing water quality conditions, the low flow characteristics of a watercourse are of interest to all stakeholders including the Ontario Ministry of the Environment and Energy. Specific uses of low flow information may include the following:

i) Instream pollutant analysis (point and non-point sources)
ii) Reservoir design (low flow augmentation)
iii) Environmental appraisals
iv) Feasibility of small hydro developments
v) Water supply and evaluation for water taking permits
vi) Base flow/groundwater recharge and/or contamination analysis
vii) Stream fisheries assessments
viii) Analyse effects of changes in watershed on low flows (eg. deforestation, urbanization)
ix) Agricultural impacts and supply
x) MISA - assessment and review
xi) Provincial discharger dilution profiles
xii) Wasteload allocation studies
xiii) Watershed planning
xiv) Contaminant transport times, for spills
xv) Strategic planning and priority setting.

The identification of low flow characteristics within a watercourse is most easily accomplished using continuous hydrometric data recorded for the stream.

A primary source of information describing drought conditions is the "Low Flow Characteristics" maps which were recently updated by Cumming Cockburn Limited for the Ministry of the Environment and Energy. This information includes tables and graphs of low flow values and statistical characteristics for both extreme value and flow duration analyses. A large data base exists with all of this data. However, the effectiveness of utilizing single station analyses is limited since a hydrometric recording gauge may not be located in the vicinity of the particular site under study. (This is becoming a more serious problem as ongoing budget constraints continue to eliminate gauging stations at various locations across the Province).

Useful techniques do not presently exist for transferring this information to ungauged sites. The use of historical techniques (eg. station proration by unit flows, area, etc.) are limited by several assumptions, including:

- ignoring the effects of regulation or upstream storage (lakes, swamps, etc.)
- assuming the watersheds are homogeneous (i.e. physiographic characteristics are ignored)
- assuming the climatic regions are homogeneous.

Cumming Cockburn Limited recently completed preliminary research programs which describes the initial stages of development of techniques to produce low flow estimates for ungauged sites for the Southwestern and West Central regions, and Central and Southeastern Regions in Ontario.

The studies included a literature review of similar relevant investigations. In all, five methods for estimating low flows were identified.

The recent investigations have led to the identification of several areas of research to be further developed for estimating low flows for ungauged watersheds. The present study was undertaken to confirm the applicability of regional methods and to modify and enhance the applicability of available methods, and to develop further insight into predicting low flow values at ungauged locations. The test areas selected were the Northwestern and Northeastern regions of the Province of Ontario (see Figure 1.1).

1.2 Study Objectives

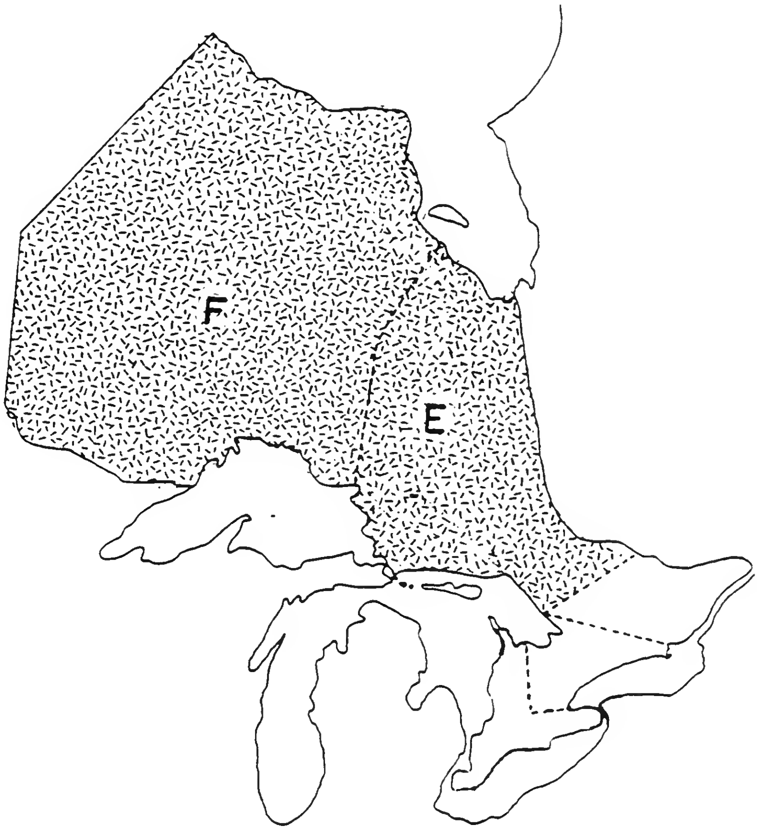
The main objective was to further refine techniques for providing estimates of low flow characteristics for ungauged streams based on the physical parameters of the watershed and appropriate meteorological variables.

It is expected that the technique could then be further developed and adapted in order to provide estimates of low flows for ungauged watersheds at other locations in the Province.

The following points summarize the focus of this investigations:

1) To develop an appropriate data base including the statistical characteristics of low flows and relevant hydrologic, physical and meteorologic characteristics of watersheds for evaluation and input to low flow prediction procedures;

2) To investigate procedures to evaluate possible trends in low flow records;



E NORTHEASTERN OF ONTARIO

F NORTHWESTERN OF ONTARIO

CCL	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	STUDY LOCATION FIGURE 1.1

3) To identify new techniques suitable for low flow analysis and to improve the predicting accuracy of low flow characteristics; and

4) To test the various methodologies for predicting low flows int he Northwestern and Northeastern regions.

5) To identify suitable techniques for application and required research/refinements (eg. by comparison of regression and mapping techniques).

The literature review is discussed in Section 2.0, and the relevant characteristics of the available data base are discussed in Section 3.0. The development of alternate regionalization techniques is discussed in Section 4.0 and testing of the procedures is summarized in Section 5.0. Conclusions and recommendations for future work are summarized in Section 6.0.

2.0 LITERATURE REVIEW

2.1 General

A review of the literature describing "Low Flow Characteristics" is beneficial for the identification of:

- existing prediction methods
- significant parameters
- new techniques
- estimation errors
- data screening techniques

This review concentrated on updating the previous review of available literature (CCL, 1990; CCL, 1991) and on identifying additional literature applicable to this Northern Regions analysis. Since the present investigation also includes trend analysis, the literature review has been divided into two parts (i.e Section 2.2.1 - Selected Low Flow Studies, and Section 2.2.2 - Selected Trend Analysis Studies).

A brief review of individual studies follows and highlights are summarized in Section 2.2.3.

2.2 Literature Review

2.2.1 Selected Low Flow Studies

Accuracy of Low Flow Characteristics Estimated by Correlation of Base Flow Measurements
(C.H. Hardison, 1972).

This study examined the inter-relationships of low flow characteristics of a stream at gauged and ungauged locations. An estimation technique based on a series of base flow measurements was developed to relate mean annual and seven day low flows at the site location. Following this, a method to determine the equivalent number of gauging years at the ungauged location that was required to produce the accuracy of the regressed base flow relationship was developed. In addition, extrapolation of the technique was extended to the more extreme low flow characteristic (i.e. $7Q_{10}$).

Two sites on the Old Mill Stream branch in Maryland with drainage areas of 11.2 sq. mi. and 22.3 sq. mi ungauged and gauged respectively, were related based upon 16 base flow measurements made at the ungaged locations. It was determined that based on the 18 year gauged data analysis, that 12 years of record would have been required at the ungauged location to produce a prediction accuracy similar to the base flow interrelationship technique.

This study also discussed similarities between one and seven day low flows and suggests that longer durations such as 30 or 60 day duration low flow depend on hydrologic factors, other than base flow recession.

The estimation technique appears to be sensitive to the data skewness with negative skew coefficient requiring more gauging years to obtain similar standard error for those series with positive skewness.

<u>Techniques of Water Resources Investigations of the USGS, Low Flow Investigations</u>
(H.C. Riggs, 1972)

"This manual described methods for defining the low flow characteristics of streams, shows how certain basin characteristics influence the mean and variability of annual low flows, and recommends procedures for data collection, analysis, and reporting".

The report indicates that at the time of its writing, estimates of low flow characteristics at ungaged locations are generally inaccurate since low flows are highly dependent on the lithology and structure of rock formations and on the amount of evaporation, neither of which has been adequately described by indices. Other parameters identified as significant are:

- precipitation over the basin in time and space
- temperature regime (i.e. storage of water as snow)
- soil and geologic characteristics

A short discussion of the accuracy of zero low flows indicates that local knowledge may be important in determining the likelihood.

Extrapolation of nearby gauged data to a few base flow measurements at an ungaged location is identified as a possible estimation technique. However, differences between drought base flows and common base flow relationships are defined as possible inaccuracies in that processes causing extreme low flow may be different than the common base flow relationships.

A comparison of using data inter-relationships at a short term gauged station to the record at a nearby long term gauged station was analyzed. It was found that more accurate results were obtained from extending a probability graph from 10 years of record at the short duration station than the results obtained by extending the record with base flow interrelationships.

It was also indicated that 10 years of record was a good minimum record length on which to base estimates of 20 year recurrence interval low flows.

This report also notes that at less frequent recurrence intervals (i.e. nQ_{20} - nQ_{100}), the effects of differences in geology and evapotranspiration become more significant.

A technique of measurements identified as seepage runs was identified as an excellent method for determining specific processes which affect low flows on a stream by stream basis. Seepage runs are when flow information is collected simultaneously along a river reach during a drought period to identify flow interrelationships.

Technical Manual for Estimating Low-Flow Frequency Characteristics of Streams in the Susquehanna River Basin
(Jaffrey T. Armbruster, 1976)

The report presented procedures for estimating low flow frequency characteristics for streams in the Susquehanna River Basin. The techniques can be used at ungauged sites as well as sites where insufficient data are available to make a reliable estimate.

Streams have been divided into two types - Major and Minor. Points on the streams with 2,000 Mi^2 (5,180 km^2) are included in the major stream category. Points on the streams with drainage area of less than 2,000 Mi^2 fall into the minor stream category.

Multiple - regression techniques were used to develop relations for estimating various duration low flows at occurrence intervals of 10, 20, 30 and 100 years for annual series data.

The form of the regression model used in the study was:

$$\log Y = \log C + b_1 \log X_1 + b_2 \log X_2 + \ldots\ldots$$

$$+ b_{n-1} \log X_{n-1} + b_n X_n$$

It is indicated that the determination of the appropriate basin characteristics is probably the most time consuming part of the computation.

Application of Statistical Low Flow Analysis As a Basis for Water Quality Planning
(Henning Rubock, 1982)

This study analyses the relations between runoff and water quality on a statistical basis. The authors indicated that it was unique because parallel measurements of runoff and water quality parameters were available. The study examined three river systems in Germany having dense population and management of runoff by reservoirs. The study concluded that it was not possible to assess water quality parameters using runoff information only. The results indicate that water quality extremes can be related to some threshold low flow values. Water quality is a function of the quantity of augmented flow and the quantity of original runoff. A technique for reservoir sizing for low flow augmentation was illustrated.

Regional Hydrologic Analysis 1. Ordinary, Weighted and Generalized Least Squares Compared
(Jerry R. Stedinger and Gary D. Tasker, 1985)

This paper compared the performance of ordinary, weighted and generalized least squares estimators of the parameters for regional hydrologic relationships in situations where available streamflow records at gauged sites can be of different and widely varying lengths and concurrent flows at different sites are cross-correlated.

A Monte Carlo study illustrated the performance of an ordinary least squares (OLS) procedures and an operational generalized least squares (GLS) procedure which accounted for an directly estimated the precision of the predictive model being fit. The GLS procedure provided:

1) More accurate parameter estimates.

2) Better estimates of the accuracy with which the regression models parameters were being estimated.

3) Almost unbiased estimates of the model error.

The OLS approach can provide very distorted estimates of the model's predictive precision (model error) and the precision with which the regression model's parameters are being estimated.

A weight least squares procedure which neglects the cross-correlations among concurrent flows does as well as the GLS procedure when the cross-correlation among concurrent flows is relatively modest.

The Monte Carlo examples also explored the value of streamflow records of different lengths in regionalization studies.

A Method of Streamflow Drought Analysis
(Emir Zelehasic and Atila Salvai, 1987)

"A method of completely describing and analyzing the stochastic process of streamflow droughts has been recommended. All important components of streamflow droughts such as deficit, duration, time of occurrence, number of streamflow droughts in a given time interval [0,t], the largest stream flow drought deficit, and the largest stream flow drought duration in a given time interval [0, t] are taken into consideration. A streamflow drought is related here to streamflow deficit. A stochastic model is presented for interpretation and analysis of the largest streamflow drought deficit below a given reference discharge and the largest streamflow drought duration concerning a time interval [0,t], at a given location of a river. The method is based on the assumption that streamflow droughts are independent, identically distributed random variables and that their occurrence is subject to the Poison probability law. This paper is actually a continuation of the previous E. Zelenhasic (1970, 1979, 1983) and P. Todorovic (1970) works on the extremes in hydrology. Application of the method is made on the 58-year record of Tisa River at Senta, Yugoslavia, and good agreement is found between the theoretical and empirical distribution functions for all analyzed drought components for the river. Only one complete example, the Sava River at Sr. Mitrovica, is given in the paper. The proposed method deals with hydrograph recessions of daily or instantaneous discharges in the region of low flows, and not with mean annual flows which were used by other investigators".

The study resulted in the following findings:

- The Zelenhasic - Todorovic flood model can be easily modified for a complete analysis of droughts

- Other characteristics of low flow that are required in Yugoslavia are recurrence interval deficit volumes and maximum n-day durations for various recurrence intervals

- A frequency duration curve is used to identify what a low flow is (i.e. flows which occur less than 90% of the record length)

- The above low flows are then assessed over the period of record, not on an annual basis, (i.e. the station analyzed in the study had 72 drought occurrences in 58 years record of which 14 years no drought occurred)

- Statistical analysis indicated that the low flows for the stations analyzed are independent, and free of trend.

A Comparison of Methods for Estimating Low Flow Characteristics of Streams
(Gary D. Tasker, 1988)

Four methods for estimating the 7-day, 10 year and 7-day, 20-year low flows for streams are compared by the bootstrap method. The bootstrap method is a Monte Carlo technique in which random samples are drawn from an unspecified sampling distribution defined from observed data. The nonparametric nature of the bootstrap makes it suitable for comparing methods based on a flow series for which the true distribution is unknown. Results show that the two methods based on hypothetical distributions (Log-Pearson III and Weibull W3) had lower mean square errors than did the Box-Cox transformation method or the log-Boughton method which is based on a fit of plotting positions.

Comparison of Method of Residuals and Cluster Analysis for Flood Regionalization
(Nageshwar R. Bhaskar, Carol A. O'Connor, 1989)

The method of residuals was used by U.S. Geological Survey (USGS) to delineate seven flood regions for the state of Kentucky. An alternative approach is to use cluster analysis in conjunction with important statistical properties of the maximum annual flood peak series. Applying the FAST-CLUS clustering procedure of the statistical analysis system, five cluster regions are identified using a similar data base as the USGS study. Flood regions delineated under these two methods of flood regionalization are then compared by examining trends in important hydrological characteristics within each of the regions, and through a discriminant analysis based upon watershed physical attributes. Results show that, although cluster regions are in no way similar to those defined by the method of residuals . nor coincident with geographical boundaries, they are more distinguishable and better discriminated in terms of the hydrological characteristics controlling flood response than the USGS regions. Furthermore, standard errors associated with the regression equations relating the log-Pearson, type III 50 year flood estimate to watershed physical attributes are comparable under the two methods of regionalization.

Low Flow Frequency Analysis Using Probability-Plot Correlation Coefficients

(Richard M. Vogel, Charles N. Kroll, 1989)

Although a vast amount of literature exists on the selection of an appropriate probability distribution for annual maximum flood flows, few studies have examined which probability distributions are most suitable to fit to sequences of annual minimum streamflows. Probability plots have been used widely in hydrology as a graphical aid to assess the goodness of fit of alternative distributions. Recently, probability-plot correlation-coefficient (PPCC) tests were introduced to test the normal, two parameter lognormal and Gumbel hypotheses. Those procedures are extended to include both regional and at-site tests for the two-parameter Weibull and lognormal distributional hypotheses. In theory, PPCC-hypothesis testing can only be developed for two-parameter distributions that exhibit a fixed shape. Nevertheless, the PPCC is a useful goodness-of-fit statistic for comparing three-parameter distributions. The PPCC derived from fitting the two and three-parameters lognormal, two and three-parameter Weibull, and log-Pearson type III distributions to sequences of annual minimum seven-day low flow at 23 sites in Massachusetts are compared. How the PPCC can be used to discriminate among both competing distributional hypotheses for the distribution of fixed shape and completing parameter-estimation procedures for the distributions with variable shape is described. An approximate regional PPCC test was developed and used to show that there is almost no evidence to contradict the hypothesis that annual minimum seven-day low flows in Massachusetts are two-parameter lognormal.

Uncertainty Analysis of Runoff Estimates from a Runoff Contour Map

(Barry P. Rochelle, Donald L. Stevens Jr., and M. Robbins Church, 1989)

"The U.S. Environmental Protection Agency (EPA) in cooperation with the U.S. Geological Survey (USGS) conducted an analysis to quantify the uncertainty associated with interpolating runoff to specific sites using a runoff contour map. Mean Annual Runoff for 93 gauged watershed were interpolated from a runoff contour map using (1) hand interpolation to the watershed outlet, (2) a computer interpolation to the watershed outlet, and (3) hand interpolation to the watershed centroid. The interpolated values were compared to the actual observed values and found that there was a bias in the average interpolated value for runoff estimated at basin outlets, with interpolated values being less than the actual. It was found that no significant difference between the hand interpolation method and the computer interpolation method except that the computer method tended to have higher variability due to factors inherent to the software used. There were no strong spatial correlations or regional patterns in the runoff interpolations, which indicates that there are no regional biases introduced in the development of the contour map.

It was determined that runoff could be estimated, on the average, within approximately 8.9 cm (3.5 in; 15 percent) of the measured value using the three methods. The results of this work indicate that runoff contour maps can be used in regional studies to estimate runoff to ungaged systems with quantifiable uncertainty".

Analysis of Winter Low Flow Rates in New Hampshire Streams
(Rae Ann Melloh, 1990)

This report investigated the regionalization of low flows in the White Mountain and Upland physiographic sections of New Hampshire. The preliminary effort established a data set that would be used in the development of improved analytical methods for estimating flows that occur in the winter. The primary objectives were to determine whether or not winter season low flows vary significantly between the physiographic areas and, if so, to provide possible explanations for this. The magnitude of basin-to-basin variation in winter low flow rates within the two physiographic sections was compared with average regional variation. The correlation between mean basin elevation and discharge per square mile was assessed as an indicator of the effect of elevation related climate gradients on stream flows. Summer low flows were also developed for use as a comparison set.

The results of the analysis indicate:

- Winter low flows occur more frequently than summer low flows for regions of high elevation

- Summer and winter low flows belong to different populations

- Winter low flow values are generally higher and increase more rapidly than summer low flows when compared to increases in drainage area

- The summer low flows are more highly correlated to elevation than are winter low flows

- Unit area flows of .5 $ft^3/s/mi^2$ (5.5 $l/s/km^2$) to .7 $ft^3/s/mi^2$ (7.7 $l/s/km^2$) were identified for the mean seven day duration winter low flows with close similarities between both regions

- Unit area flows of 0.1 $ft^3/s/mi^2$ (1.1 $l/s/km^2$) to 0.03 $ft^3/s/mi^2$ (0.3 $l/s/km^2$) were identified for the mean seven day duration summer flows. The two regions differed substantially with respect to flow series

The following equations were developed for winter flows:

7Qm = 0.51 DA + 0.41	R^2 = .89 SE = 12.0 White Mountain Streams
7Qm = 0.71 DA - 11.29	R^2 = .93 SE = 7.8 Upland Streams

The following equations were developed for summer flows:

7Qm = 0.34 DA - 2.02	R^2 = .62 SE = 17.7 White Mountain Streams
7Qm = 0.16 DA - 3.33	R^2 = .71 SE = 4.2 Upland Streams

<u>Errors in Estimating Stream Flow Parameters and Storages for Ungaged Catchments</u>
(K.C. Gan, T.A. McMahon and I.C. O'Neill, 1990)

This study developed predictive equations for the mean and the coefficient of variation of annual stream flow for southeast Australia. The significant parameters were identified as drainage area and the mean annual rainfall.

$$Qm = 9.3 \times 10^{-6}\ DA^{0.99}\ MAR^{1.48} \qquad R^2 = 0.97,\ SE = -35\% + 54\%,\ N = 80$$

Sensitivity analysis of drainage area size, record length and subregional analysis were examined. It was determined that record lengths had insignificant affects, subregions were not significantly different than the complete region and drainage area size has some affect but further investigation is required.

Errors associated with catchment storage estimates based on the prediction equations were illustrated.

Generalized Low-Flow Frequency Relationships for Ungauged Sites in Massachusetts
(Richard M. Vogel and Charles N. Kroll, 1990)

This study developed generalized regional regression equations for estimating the n-day, T-year low flow discharge nQ_T at ungauged sites, where n=3, 7, 14 and 30 days. A two-parameters log normal distribution was fit to sequences of annual minimum n-day low-flows and the estimated parameters of the log normal distribution were then related to two drainage basin characteristics: drainage area and relief. The resulting models were general, simple to use and about as precise as most previous models that only provided estimates of a single statistic such as $7Q_{10}$.

Comparisons were provided of the impact of using ordinary least squares (OLS) regression, generalized least squares (GLS) regressions and streamflow record augmentation procedures to fit regional low-flow frequency models. It was conducted that the generalized least squares regression procedures led to almost identical regional regression model parameter estimates when compared with the ordinary least squares procedures. In general, GLS procedures will have significant advantages over OLS procedures in studies which seek to include very short records such as at partial record sites. In such instances GLS procedures can lead to significant improvements because the number of sites included in the analysis can be increased considerably.

Practical Aspects of Low Flow Frequency Analysis
(R.J. Nathan and T.A. McMahon, 1990)

"This paper considers some practical aspects concerning the application of the Weibull distribution to low flow frequency analysis. Two and Three-parameter forms of the distribution are fitted to a total of 987 distributions derived from the daily flow data of 134 catchments located in southeastern Australia. The relative performance of three estimation methods (moments, maximum likelihood, and probability weighted moments) is investigated, and it is found that the different estimation methods provide distinct sets of quantile estimates. The method of probability weighted moments is more likely to give unsatisfactory estimates of the smallest drought and in general tends to yield less severe estimates of drought volumes relative to the other two methods. The method of maximum likelihood, however, occasionally provides estimates of drought volumes that are many times greater than that yielded by the methods moments or probability weighted moments. In addition, the differences between low flow frequency estimates based on calendar and hydrologic years is investigated".

The following points summarize the main findings:

- Compared to a water year basis the use of a calendar year was found to be more conservative for annual minima.

- The study analysed 134 catchments in southeast Australia with an average record length of 21 years

- Low flow estimates based on calendar year are less than (approximately 12%) those based on a hydrologic year (i.e. wettest month is start of hydrologic year) for short duration low flows (i.e. $n < 60$ days)

It is noted in the study that 85 of 1072 samples contained too few non-zero flows and were subsequently removed from further examination.

The study results confirmed that different estimation methods produce different low flow results (i.e. 5% to 20% for $7Q_2$ and $7Q_{20}$) but the differences decrease as sample size increases.

It is recommended in the study that adoption of a single technique would be best for regional analysis since result variability would be catchment process dependent and not estimation technique dependent.

The Use of L-moments for Regionalizing Flow Records in the Rio Uruguai Basin: A Case Study
(Robin T. Clarke and Luis Edgar, Montenego Terrazas, 1990)

This paper explores the use of L-moments to regionalize annual maximum mean daily discharge (y1), using data from 29 sub-basins of the Rio Uruguai in Southern Brazil. As first assumptions, a Gumbel distribution was taken to describe the probability distribution of y1, and basin area was taken as the principle basin characteristic in regression analyses. Multivariable (as distinct from multivariate) regressions were used to obtain estimates of (a) L-moments of y1 for ungauged basins; (b) conventional moments of y1 for ungauged basins, and two sets of moments were used to derive estimates of:

i) Gumbel parameters and hence;
ii) estimates of y1 with given return periods, together with their approximate confidence limits.

Use of L-moments gave estimates with narrower confidence limits than conventional moments, although the difference was not large.

<u>The Weibull Distribution Applied to Regional Low Flow Frequency Analysis</u>
(P.J. Pilon, 1990)

The inability to estimate accurately low flow of specific duration and probability for ungauged basins has long plagued the practitioner. The index-flood method is one tool which may assist in this regard, through its adaptation to low flows. This paper outlines the extension of the index flood method to low flow analysis when the regional distribution is assumed to be the three-parameter Weibull (W3). Flows corresponding to specific return periods of nonexceedance can be made dimensionless by dividing by some chosen index low flow.

Within a homogenous region, the dimensionless frequency curve at any station is considered a random sample. The best representation of the regional characteristics is obtained by averaging the dimensionless curves for all stations in the region. The resulting average dimensionless curve is the regional dimensionless frequency curve and is considered applicable throughout the region, providing the conditions of homogeneity are met. If the n-year low flow at an ungauged site can be estimated, the entire low flow frequency relationship can be developed by multiplying by the appropriate ratios of the dimensionless curve.

A homogeneity test is applied to the region. The authors suggested that L-moments ratio diagrams could be used to study the appropriateness of the choice of the parent distribution. When the parent is W3, the derived technique may provide useful results in many practical situations.

<u>Regional Hydrology of New Brunswick</u>
(Brian C. Burrell and James E. Anderson, 1991)

In this paper, an overview of the surface water hydrology of New Brunswick was presented; primarily within the context of high and low flows. The influence of physiographic and climatic factors on streamflows was examined and the delineation of zones of hydrologic similarity based upon these parameters were discussed. Regions of hydrologic homogeneity were presented and reviewed relative to the streamflow gauging network and the estimation of streamflows at ungauged sites.

It reviewed the development of statistical relationships between peak flows or low flows for specified recurrence intervals and the physiographic, hydrologic and climatic characteristics of gauged watersheds. The presentation of these relationships in a form readily useable for streamflow estimation was discussed.

The low flow regression analysis were performed for various regions and different basin sizes. The northern region equation is in the general form

$$LF_{T,D} = (C*DA^{0.5} + d*MAP^{0.5} + K)^2$$

For the southern region, two equations were developed with one equation for basin drainage areas greater than or equal to 400 km^2 and the other equation for drainage basin areas less than 400 km^2.

Regionalization of Low Flow In Central and Southern Alberta
(V.K. Khanna, 1992)

This paper developed regional models for the estimation of low flow characteristics at ungauged sites in six basins of central and Southern Alberta. eighty natural flow gauging stations were used in the regionalization study. Regional models are developed using the ordinary least squares (OLS) techniques to estimate N-day low flow at ungauged sites in the study area, where N could vary from 1 to 31 days.

The approach consists of finding the relationship of the 3, 7, 14, 21, and 28 day mean low flows to the 10-day mean low flow with a two year return period D_2 (10). The relationship is of the following form:

$$D_2 (N) = D_2 (10) + (N - 10) * GRDM$$

where:

N = Duration of mean (with a 2 year return period) low flow varied from 3 to 28 days.

GRDM = Slope of mean flow duration relationship

$$= \frac{\sum ((N - 10) * D_2 (10))}{\sum (N - 10)^2}$$

The models were recommended for GRDM for each studied basin to estimate the two year N-day mean flows, where N varies from 1 to 31 days. The models are used in conjunction with the recommended models D_2 (10) to estimate the low flow characteristics at ungauged sites.

The standard error of estimates of the recommended regional models in the study varies from 18.5 to 40.6 percent.

Working Group II Receiving Water Assessment Techniques and Analysis, Low Flow Design Criteria
(Dr. L. Logan)

This paper examines the affects of using low flow statistics other than $7Q_{20}$ when considering wastewater assimilation (i.e. $7Q_2$ and $7Q_{10}$). Economic and risk of failure is examined with respect to a number of Ontario Streams. The study recommends that $7Q_{20}$ should be the low flow design criterion for Ontario. There is also some discussion of regulation (i.e. 50% of Ontario Streams are considered regulated) and its affects on risk of failure to meet the quality objectives of facility operation.

2.2.2 Selected Trend Analysis Studies

An Application of Time Series Analysis in Hydrometric Network Evaluation
(R.G. Boals, 1979)

This report analyses time series modelling techniques for illustrating trends for two northern Manitoba streams. Types of data collection activities are discussed in addition to a network management scheme for base and satellite monitoring locations. Auto-correlation and spectral density functions were used to analyze the stream flow data. Both stations indicated significant trend components with respect to average monthly flows.

Assessment of Water Quality Time Series
(A. Ian McLeod, Keith W. Hipel and Fernando Comacho, 1983)

"A general methodology is described for identifying and statistically modelling trends which may be contained in a water quality time series. A range of useful exploratory data analysis tools are suggested for discovering important patterns and statistical characteristics of the data such as trends caused by external interventions. To estimate the entries in an evenly spaced time series when data are available at irregular time intervals, a new procedure based upon seasonal adjustment is described. Intervention analysis is employed at the confirmatory data

analysis stage to rigorously model changes in the mean levels of a series which are identified using exploratory data analysis techniques. Furthermore, intervention analysis can be utilized for estimating missing observations when they are not too numerous. The effects of cutting down a forest upon various water quality variable and also the consequences of acid rain upon the alkalinity in a stream provide illustrative applications which demonstrate the effectiveness of the methodology".

Nonparametric Approaches to Environmental Impact Assessment
(There were nine papers dealing with nonparametric testing and estimation methods in Water Resources Bulletin Vol 24, No. 3, 1988)

Various nonparametric trends detection approaches were described. A distinct advantage of nonparametric tests is that they are usually very effective when applied to "messy" environmental data which may contain many missing observations and not be normally distributed. By applying their enhanced approaches for nonparametric methods to water quality time series, as well as employing well designed simulation experiments, the authors of the papers clearly demonstrate the efficacy of utilizing nonparametric tests in environmental Impact assessment.

The following briefly summarizes the approaches and the main conclusions for some of these papers:

Multivariate Nonparametric Tests For Trend In Water Quality
(Dennis P. Lettenmaier, 1988)

A test which is sensitive to up and down trends and has power approaching that of the covariance sum method, was described. A variation of a contrast test for discriminating trend directions and magnitudes among variables or seasons where correlation between seasons or variables is present was described, and tests of its performance reported.

Nonparametric Tests for Trend Detection In Water Quality Time Series
(David Berryman, Bernard Bobee, et al, 1988)

A review of nonparametric tests for trend leads to the conclusion that Mann-Whitney, Spearman and Kendall tests are the best choice for trend detection in water quality time series. These tests have been adapted to account for dependence and seasonality in such series. For monotonic trends, a procedures allowing to select the pertinent tests considering the characteristics of time series was proposed and the practical limitations of the tests were also brought out. When a

time series can be tested with the Mann-Whitney, Kendall, Spearman, or Lettenmaier test, the number of observations required to detect trends of a given magnitude, for selected significance and power levels can be calculated with the power function of the t test.

Parametric and Nonparametric Tests for Dependant Data
(A. H. El-Shaarawi and Eivind Damsleth, 1988)

Simulation and aneclytical results shown that ignoring serial dependence can have serious effects on the performance of the t, sign and Wilcoxen tests. In particular, the true significance levels of these tests were altered significantly from the intended nominal levels. Modifications for these tests were given and shown to have the correct significance levels. Furthermore, an estimate of serial correlation was suggested for binary data and evaluated by simulation.

Statistical Methods and Sampling Design for Estimating Step Trends in Surface-Water Quality
(Robert M. Hirsch, 1988)

The paper addressed two components of the problem of estimating the magnitude of step trends in surface water quality. The first was finding a robust estimator appropriate to the data characteristics expected in water-quality time series. The Hodges-Lehmann class of estimators was found to be robust in comparison to other nonparametric and moment-based estimators. A seasonal Hodges-Lehmann estimator was developed and shown to have desirable properties. Second, the effectiveness of various sampling strategies are examined using Monte Carlo simulation coupled with application at this estimator.

Robust Trend Assessment of Water Quality Data Series
(Byron Bodo, Keith Hipel, A.I. McLeod, 1989)

This paper discusses the reasons for trend analysis particularly with the Ontario Provincial Water Quality Monitoring Network (PWQMN). Discussions with respect to the difficulties related to water quality data sets are highlighted (i.e. uneven spacing on time, background variability, non-normality, numerous outlines and seasonal periodicity). While trend tests (i.e. Mann Kendall) are robust, they depend on monotonic trends (i.e. trends which proceed in one direction over time). Graphical procedures for trend analysis as corroborative evidence are illustrated. A main finding was that graphical procedures based on a Robust Locally Weighted Regression (RLWR) technique provided good results. It should be noted that RLWR using F values of 12 percent were ideal for smoothing seasonality and F values of 75 percent were good for illustrating annual trends.

Identification of Large-Scale Spatial Trends in Hydrologic Data
(Harishar Rajaram and Dennis McLaughlin, 1990)

It is often useful to distinguish different scales of variability in hydrologic properties. In the simplest two-scale case, large-scale fluctuations about this trend can be viewed as random residual. This paper described a method for estimating spatial trends from scattered field measurements.

The basic concept is to treat both the trend and the residual as stationary random functions. These functions are distinguished by their spatial spectral (or covariance) properties, which may be estimated from available data or simply hypothesized.

Two versions of a general algorithm for estimating spatial trends were presented:

1) A discrete version which is useful in practical applications where data are limited and irregularly spaced.

2) A continuous version which can be used to study the effects of using incorrect spectral parameters. Applications of the discrete algorithm to both synthetically generated data and field measurements yield satisfactory trend estimates. An analysis based on the continuous algorithm showed that the estimation error lower bound for these applications depends on two dimensions ratios, that is, the scale disparity (ratio of the trend and residual correlation scales) and the signal-to-noise ratio (ratio of the trend and residual variances). These ratios may be used to evaluate the feasibility of trend estimation before field samples are actually collected.

Trend Analysis Methodology for Water Quality Time Series
(A.I. McLeod, K.W. Kipel, 1990)

This study presents a general trend analysis methodology for detecting and modelling trends in water quality time series. The procedure is developed for problematic data series with characteristics such as non-normal positively skewed populations, irregularly spaced instantaneous observations, seasonal periodicities and coverable. Graphical methods, for example time series plots, robust regression smooths and box and whisker plots are used for illustrating trends. Non-parametric techniques are based on Kendall's rank correlation coefficient. Spearman's partial rank correlation is also used for analyzing trends especially for seasonal dependant and missing data series. The study illustrates the methodology on the Grand and Saugeen Rivers in southwestern Ontario.

Note: These techniques were subsequently used extensively in the present investigation. Further detailed information is given in Section 3.2.

Exploratory Data Analysis
(Rory M. Leith, Keith W. Hipel and Herman Goertz, 1991)

"Exploratory data analysis techniques are used to detect trends and other statistical characteristics in nine streamflow time series at both the annual and monthly levels. For convenience of interpretation, the output from the analysis is displayed graphically, along with some numerical results from appropriate statistical tests. As well as providing indications and statistical tests of trends, non-normal behaviour and auto-correlated behaviour in flow sequences, exploratory data analysis may be used to place any particular response or collection of responses in context against the range of observed values, thus indicating periods of unusual flow conditions."

Nine stations are analyzed, five located in Ontario and four located in British Columbia. The report results indicate that two out of five Ontario stations illustrate increasing trend for mean annual flows. It is interesting to note that stations 04CJ001, 02AD008 (part of the subset of data available, for use in this report) are identified as having inconsistent record statistics and heavily regulated tendencies respectfully.

Selection of Methods for the Detection and Estimation of Trends in Water Quality
(Robert M. Hirsch, Richard B. Alexander, and Richard A. Smith, 1991)

This paper summarizes and examines some of the major issues and choices involved in detecting and estimating the magnitude of temporal trends in measures of stream water quality. The first issue is the type of trend hypothesis to examine; namely step trends versus monotonic trend. The second relates to the general category of statistical methods to employ, i.e. parametric versus nonparametric. The third issue relates to the kind of data to analyse; concentration data versus flux data. The fourth relates to issues of data manipulation to achieve the best results from the trend analysis. These issues include the use of mathematical transformations of the data and the removal of natural sources of variability in water quality due to seasonal and stream discharge variations. The final issue relates to the choice of a trend technique for the analysis of data records with censored or "less than" values.

The type of trend analysis (i.e. step trends versus monotonic trends) was illustrated. For example, step trends are used to establish that a data sample may be made up of two or more distinct populations and a monotonic trend is a continuous increasing or decreasing trend over time. Problems and possible solutions to temporal inconsistencies for groups of records is detailed.

Parametric and non-parametric tests are compared and it was concluded that the more non-normal the data set was, the better the results are for parametric tests. However, the results indicate for large samples the modest advantage of efficiency for parametric tests are not comparable to the deficiency in applying parametric tests with biases of assumptions inherently involved in applying such techniques, and hence non-parametric tests are recommended for large group data sets.

Statistical Estimation and Interpretation of Trends in Water Quality Time Series (Lena Zetterqvist, 1991)

Three approaches to trend analysis of water quality time series were discussed:

1) seasonal model, with a test for trend based on ranks of observations, with observations assumed to be dependant;

2) transfer function noise model, in which co-variate series may be included by means of transfer functions, with the remaining noise modeled as a seasonal auto-regressive moving average process;

3) component model, with the noise decomposed into their ability to include co-variate series, possibility of interpretation of trends, treatment of seasonal variation and serial dependence, and robustness for outlier. The component model has been regarded as the most realistic and the most informative of the three approaches.

2.2.3 Summary

A summary of relevant information for various investigations which included development of regional low flow prediction methods is given in Table 2.1.

In undertaking a review of the literature in previous investigations it was found that many investigators have analysed low flow characteristics over durations from 1 to 273 days in length, for return periods of 1 to 100 years. In general, it was determined that the Gumbel III and Log-

Pearson III distributions best fit the samples of low flow data for gauged streams (Tasker, 1987, Condie and Nix, 1975, Matalas, 1965 and Table 2.1). Several investigations considered techniques for predicting selected low flow characteristics while very few investigations have considered techniques for developing regionalized flow duration curves.

Parameters found to be significant in regression equations generally tended to be drainage area, base flow index, mean annual precipitation, area controlled by lakes and swamps, watershed relief, stream length, mean annual snowfall, mean annual evaporation, groundwater fluctuations, mean annual runoff and soil index. However, some parameters that were not found to be highly correlated in one region were found to be important in other regions (Institute of Hydrology, 1980).

With reference to the available literature, the previous investigation in Southern Ontario included the following parameters in development of the physiographic, meteorologic and hydrometric data base; drainage area (DA), mean annual snowfall (MAS), mean annual precipitation (MAP), mean annual runoff (MAR), mean annual evaporation (EVA), area controlled by lakes and swamps (ACLS), stream length (LNTH) and Base Flow Index (BFI).

Recent investigations (Cumming Cockburn Limited, 1990) also recommended that the Ministry of Environment and Energy should continue use of the $7Q_{20}$ as a prime indicator of low flows for the Province of Ontario.

The following additional points and relevant information on analysis and regionalization of low flows and trends summarize the main highlights of the literature review as related to the objectives of this investigation.

<u>Low Flows</u>

With regard to low flow characteristics, the review of literature identified the following points of interest:

- Winter low flows appear to have greater magnitude than summer low flows

- Winter and summer low flows may belong to distinct populations in some areas

- Some data records have subsets which belong to different populations

- Record lengths of 10 years are a good minimum estimator for 20 year recurrence low flow

- Some years the drought statistic may not be significant in large record lengths compared to several base flow periods in one dry year

- Calendar year analysis of low flow characteristics provides more conservative results than those based on a water year for short durations

- The most common distribution for analysing low flow characteristics are the Weibull, two parameter log normal, Log Pearson Type III and Gumbel

- The use of L-moments gave estimates with narrower confidence limits than conventional moments, although the difference was not larger

With regard to regionalization of low flows the literature identified the following points of interest (see also Table 2.1):

- Long duration low flows may be affected by different physiographic and climatic characteristics

- Elevation related effects of climate parameters indicate high correlation coefficients of elevation to low flows

- Intercorrelation of base flows from nearby gauges is a good method of extending short record lengths to produce high recurrence interval estimates (i.e. base flows from a 2 year record length can be regressed against base flows of a nearby hydrologically similar long term station to predict nQ_{20} extreme values)

- Isoline analysis of flow characteristics provides a fairly robust estimation technique for ungauged watersheds

- Evapotranspiration is an important hydrometerologic process affecting low flows

- Several recent studies have developed statistical tests for identifying regions with homogeneous low flow characteristics.

TABLE 2.1
SUMMARY OF LITERATURE REVIEW

Study	No. of Stations	Distri- bution	Method	Parameters Examined	General Form of Equations
Wright, 1970*			Regression	DA,BS,MAP	MAM = f(Da, BS) MAM = f(DA, BS, MAP)
Osborn, 1974*	20		Index Regression	Q7L1P,P,DA,H,CL,DD	log $7Q_2$ = f(DA, H, Q7LIP, P)
Taster, 1975*		LN III	Regression		$7Q_{10}$ = f(DA, MAP, SI)
Armbruster, 1976a* Armbruster, 1976b* Armbruster, 1976c*	104 115	 Pearson Type III	Regression Regression Index	DA,CS,BL,EL,FC,MAP,ACLS,MAS ,SI,MAP, CF, DA DA,MAP	log $7Q_{10}$ = f(DA, MAP, SI) $7Q^{10}$ = f(DA, MAP, CF) LF = f(DA,MAP)
Boyer, 1977*	12	G	Regression	DA,CO,EL,LAT,LNTH,WF,T_{10},R_{10}	In ($7Q_{10}$) = f (CO, LNTH, WF, T_{10}, R_{10}
Env. Cda., 1978*	11	G	Regression	DA,R,AS,AL,ALS,OB,LEN,DD, SLP,EL,MAP	Correlation Matrix only produced
MacLaren Plansearch, 1981*	9	Eye Fit	Regression	DA,SI,ALS	Q_1 = f(DA, SI, ALS) Q_2 = f(DA, SI, ALS)
Condie, 1983*	74	G	Regression	DA,MAP,BFI	MED(10) = f(DA, BFI) GRADMEN = f($(MED(10))^5$)
Inst. of Hydrology, 1986*	232	LN	Regression	BFI,MAP,ACLS	$(Q95(10)^{1/2}$ = f(BFI, MAP, ACLS) $(Q95(10)^{1/2}$ = f(BFI, ACLS)
Rochelle, 1989	93		Runoff Contour Map		
Cumming Cockburn, 1990*	65	3PLN	Regression	DA,BFI,LNTH	nQy = f(DA, BFI, LNTH)
Gray, 1990	80		Regression	DA,MAR	LF = f(DA, MAR)
Inst. of Hydrology, 1990*		G	Regression	Q_{95}(10),BFI,DA,MAP, LNTH	$Q_{95}(10) = F(BFI)^5, (DA)^5, (LNTH)^5$ $Q_{95}(10) = F(BFI)^5, (DA)^5, (LNTH)^5$ (100_2) = f(BFI) (1002) = f(BFI, MAP)
K. C. Gan, 1990	N/A	N/A	Regression	N/A	Qm = A* DA^{B}* MAR^{C}
Pilon, 1990	11	Weibull	Regional Frequency Curve	Regionalized Weibull parameters A,E,U	
Rae Ann Melloh, 1990	N/A	N/A	Regression	N/A	$7Q_m$ = f(DA)
U.S. Army Corps of Engineer, 1990	16		Regression	Elev.,DA,R^2	7Qm = f(DA,R^2)
Vogel & Kroll, 1990*	23	LN	Regression	DA,H	7Qy = f(DA, H)
Burrel, 1991			Regression	DA,MAP	$LF_{T,D}$ = f(DA,MAP)
Khanna, 1992	80	W3 and 3LN	Regression	GRDM, DA, BFI, LNTH, ELEVC, SSI, FOREST, PPT, DISTC, SLOPE, LATC, LONGC, HYDRAD	LN($10Q_2$) = A*LN(HYDRAD) + B*LN(LATC) + C*LN(LONGC) + D

* Source: Regional Analysis of Low Flow Characteristics Central and Southeastern Regions, Cumming Cockburn Limited, 1991

Trends

With regard to analysis of trend in low flow series, the review of literature identified the following points of interest:

- Analysis of average annual flows found some evidence of trend for many station records
- Previous studies have identified significant trend components with respect to some flow characteristics (i.e. average monthly flows, Boals 1979, and mean annual flows, Leith 1991) for some hydrometric stations in Ontario
- Non parametric tests are preferable due to inherent assumptions which must be made to apply parametric tests
- The Mann and Kendall test for monotonic trends is a good indicator for trend significance and direction
- Other trend detention methodologies include Mann-Whitney, Spearman and Lettenmaier tests
- Graphical procedures are important for corroboration of trend statistics
- The robust locally weighted regression smoothed technique illustrates trends in noisy data.

3.0 DATA BASE

3.1 General

The Northwestern and Northeastern regions identified by the Ministry of the Environment define the study area. One hundred and ninety-four (194) hydrometric stations were identified in the region for this analysis based upon the period of record and other station characteristics. Low flow characteristics for ninety-three (93) of these stations were analyzed to develop estimation techniques. Twenty-one of those remaining were set aside for testing of prediction methods. The remaining stations were omitted from the study based on selective screening criteria. (Station screening and selection is discussed in Section 3.3.2.)

Preliminary investigations were undertaken using the inhouse computerized data base. This data base was completed with flow records only extending to 1986 (due to availability early in the study). The methodology for analyzing extreme low flows and determining relevant recurrent intervals is discussed in the Low Flow Characteristics in Ontario report, Cumming Cockburn Limited, Ministry of the Environment, 1988

Flow records for the period of 1987-1990 were subsequently made available for each of the stations in Northern Ontario regions as the investigations proceeded. These new records possess more useful information which makes it possible to obtain more accurate results. Furthermore, among the 194 hydrometric stations, seventeen (17) are new stations which have more than ten years' flow records available for analysis due to the additional four year period (1987-1990). Eight (8) of the new stations were put into the data base for low flow regionalization. The remaining new stations were reserved for testing.

Statistical tests for independence, randomness, trend and data homogeneity were undertaken for 149 stations (including the stations reserved for testing) for the purpose of station screening. Results of statistical testing are summarized in Tables 3.1 (for the available data base to 1990) (additional information on statistical tests for trend analysis is given in Section 3.2 and Appendix A). The remaining 45 stations are classified as multiple station (21), highly regulated (13) and undeterminable drainage area (11). Significant trend, lack of randomness and non-homogeneity was detected for a few of the low flow data. Nineteen (19) stations which showed significant trend together with non-randomness and non-homogeneity were screened out of the analysis. Section 3.2 describes the methods used in this study to analyse trend in low flow records. It should be noted that there are sixteen (16) stations records which contain too many

TABLE 3.1(a)
STATISTICAL TEST RESULTS
NORTHWESTERN REGION (1990)

Station	# of	Region	Spearman Independence						Spearman Trend						Run Test For Randomness									Mann-Whitney For Homogeneity								R/N
			Rank	T	Critical T		Indicator		Rank	T	Critical T		Indicator		Run #		Range 5%		Zm	Critical Zm		Indicator		U	Critical		Zm	Critical Zm		Indicator		
Number	Years	Code	Order		5%	1%	5%	1%	Order		5%	1%	5%	1%	N1	N2	Low	High		5%	1%	5%	1%		5%	1%		5%	1%	5%	1%	Code
02AA001	68	3	0	0	1.67	2.39	Yes	Yes	-0.12	-0.99	-2	-2.66	No	No	34	34			1.71	1.96	2.58	Yes	Yes				-0.81	-1.65	-2.33	Yes	Yes	N
02AB004	68	3	0	0	1.67	2.39	Yes	Yes	0.321	2.751	2	2.66	Yes	Yes	24	32			2.873	1.98	2.56	No	No				-2.02	-1.65	-2.33	No	Yes	R
02AB008	64	3	0	0	1.67	2.39	Yes	Yes	0.665	1.484	2	2.66	No	No	32	32			1.28	1.96		Yes	Yes				-2.82	-1.65	-2.33	No	No	R
02AB009	34	3	0	0	1.69	2.45	Yes	Yes	-0.1	-0.55	-2.03	-2.74	No	No	(15) 17	17	12	24				Yes	Yes	129	96	77				Yes	Yes	R
02AB010	68	3	0	0	1.67	2.39	Yes	Yes	0.034	0.274	2	2.66	No	No	34	34			2.2	1.96	2.58	No	Yes				-1.73	-1.65	-2.33	No	Yes	R
02AB013	40	3	0	0	1.69	2.43	Yes	Yes	0.58	4.44	2.03	2.71	Yes	Yes	(10) 16	19	13	24				No	No	134	138	114				Yes	Yes	R
02AB014	19	3	0	0	1.75	2.58	Yes	Yes	-0.03	-0.12	-2.11	-2.9	No	No	(9) 8	9	6	13				Yes	Yes	38	24	16				Yes	Yes	R
02AB015	14	3	0	0	1.8	2.72	Yes	Yes	0.24	0.86	2.18	3.08	No	No	(7) 7	7	4	12				Yes	Yes	19.5						Yes	Yes	N
02AB016	14	3	0	0	1.8	2.72	Yes	Yes	-0.21	-0.74	-2.2	-3.06	No	No	(6) 7	7	4	12				Yes	Yes	19.5						Yes	Yes	R
02AB017	11	3	0	0	1.86	2.9	Yes	Yes	0.141	-0.53	-2.02	-2.69	No	No					0	1.96		Yes	Yes				-0.02	-1.65	-2.33	Yes	Yes	R
02AC001	20	3	0	0	1.74	2.57	Yes	Yes	-0.08	-0.98	-2.1	-2.88	No	No	(8) 10	10	7	15				Yes	Yes	34.5	27	19				Yes	Yes	N
02AD009	48	3	0	0	1.69	2.43	Yes	Yes	0.483	3.45	2.02	2.71	Yes	Yes	(13) 20	20	15	27				No	No				-2.82	-1.65	-2.33	No	No	R
02AD010	20	3	0	0	1.74	2.57	Yes	Yes	0.11	0.48	2.1	2.88	No	No	(6) 10	10	7	5				No	No	46	27	19				Yes	Yes	N
02AE001	17	3	0	0	1.76	2.82	Yes	Yes	-0.43	-1.85	-2.13	-2.95	No	No	(5) 6	6	5	13				Yes	Yes	15	18	11				No	Yes	N
02BA002	21	3	0	0	1.73	2.55	Yes	Yes	0.18	0.6	2.09	2.88	No	No	(5) 9	10						No	No	48.5	31	22				Yes	Yes	N
02BA003	19	3	0	0	1.75	2.58	Yes	Yes	0.21	0.67	2.11	2.9	No	No	(6) 9	9	6	14				Yes	Yes	44	27	18				Yes	Yes	N
02BB002	24	3	0	0	1.72	2.52	Yes	Yes	0.463	2.45	2.07	2.82	Yes	No	(12) 12	12	8	18				Yes	Yes	38	42	31				No	Yes	N
02BB003	21	3	0	0	1.73	2.55	Yes	Yes	-0.08	-0.35	-2.09	-2.88	No	No	(5) 10	10	7	15				No	No	40	31	32				Yes	Yes	N
04CA002	14	1	0	0	1.8	2.72	Yes	Yes	0.14	0.5	2.18	3.08	No	No	(8) 7	7	4	12				Yes	Yes	24						Yes	Yes	N
04CA003	24	1	0	0	1.72	2.52	Yes	Yes	-0.31	-1.51	-2.07	-2.82	No	No	(7) 11	11	8	16				No	Yes	41.5	42	31				No	Yes	N
04CB001	24	1	0	0	1.72	2.52	Yes	Yes	0.61	3.61	2.07	2.62	Yes	Yes	(10) 12	12	8	18				Yes	Yes	34	42	31				No	Yes	N
04CC001	19	1	0	0	1.75	2.58	Yes	Yes	0.08	0.34	2.11	2.9	No	No	(9) 9	9	6	14				Yes	Yes	44	24	16				Yes	Yes	N
04CD002	20	1	0	0	1.74	2.57	Yes	Yes	0.355	1.6	2.1	2.88	No	No	(10) 10	10	7	15				Yes	Yes	48	27	19				Yes	Yes	N
04CE002	23	1	0	0	1.73	2.53	Yes	Yes	0.06	0.28	2.08	2.63	No	No	(9) 11	11	8	16				Yes	Yes	84.5	38	28				Yes	Yes	N
04DA001	25	1	0	0	1.72	2.51	Yes	Yes	0.53	2.98	2.07	2.61	Yes	Yes	(8) 12	12	8	16				Yes	Yes	27	47	35				No	No	N
04DB001	25	1	0	0	1.72	2.51	Yes	Yes	0.07	0.31	2.07	2.61	No	No	(10) 12	1	8	18				Yes	Yes	61	47	35				Yes	Yes	N
04DC001	14	1	0	0	1.72	2.51	Yes	Yes	0.54	3.11	2.07	2.81	Yes	Yes	(14) 12	12	8	18				Yes	Yes	26	47	35				No	No	N
04DC002	24	1	0	0	1.72	2.51	Yes	Yes	0.15	0.71	2.07	2.62	No	No	(14) 12	12	8	18				Yes	Yes	70	42	31				Yes	Yes	N
04EA001	23	1	0	0	1.73	2.53	Yes	Yes	0.37	1.82	2.08	2.63	No	No	(12) 11	11	8	18				Yes	Yes	50	36	28				Yes	Yes	N
04FA001	25	1	0	0	1.72	2.51	Yes	Yes	0.6	3.61	2.07	2.61	Yes	Yes	(8) 12	12	8	18				Yes	Yes	36.5	47	35				No	Yes	R
04FA002	24	1	0	0	1.72	2.52	Yes	Yes	0.53	2.89	2.07	2.62	Yes	Yes	(6) 12	12	8	16				No	No	31	42	31				No	Yes	R
04FA003	25	1	0	0	1.72	2.51	Yes	Yes	0.81	3.71	2.07	2.61	Yes	Yes	(10) 12	12	6	18				Yes	Yes	36	47	35				No	Yes	N
04FB001	24	1	0	0	1.72	2.52	Yes	Yes	0.4	2.04	2.07	2.62	No	No	(6) 12	12	6	16				No	Yes	43	42	31				Yes	Yes	N
04FC001	23	1	0	0	1.73	2.53	Yes	Yes	0.46	2.36	2.08	2.63	Yes	No	(10) 11	11	6	16				Yes	Yes	42	38	26				Yes	Yes	N
04GA002	23	3	0	0	1.73	2.55	Yes	Yes	0.18	0.79	2.09	2.68	No	No	(12) 11	11	7	15				Yes	Yes	51	31	22				Yes	Yes	N
04GB001	50	3	0	0	1.68	2.41	Yes	Yes	0.29	2.13	2.01	2.69	Yes	No	(2) 0	2	1	-1				No	Yes				-1.43	-1.65	-2.33	Yes	Yes	R
04GB004	20	3	0	0	1.74	2.57	Yes	Yes	0.09	0.38	2.1	2.68	No	No	(10) 10	10	7	15				Yes	Yes	47	27	19				Yes	Yes	N
04GC002	16	1	0	0	1.77	2.65	Yes	Yes	0.31	1.22	2.15	3	No	No	(5) 6	8	5	13				Yes	Yes	23						Yes	Yes	R
04GD001	22	1	0	0	1.72	2.51	Yes	Yes	0.84	3.99	2.07	2.61	Yes	Yes	(10) 12	12	8	16				Yes	Yes	25	47	35				No	No	R
04JA002	37	1	0	0	1.69	2.44	Yes	Yes	0.09	0.51	2.03	2.73	No	No	(17) 18	18	13	25				Yes	Yes	138	118	94				Yes	Yes	N
04JC002	41	1	0	0	1.69	2.43	Yes	Yes	-0.15	-0.93	-2.02	-2.71	No	No	(14) 19	20	14	26				Yes	Yes				-0.51	-1.65	-2.33	Yes	Yes	N
04JC003	37	1	0	0	1.69	2.44	Yes	Yes	0.19	1.15	2.03	2.73	No	No	(22) 18	18	13	25				Yes	Yes	154.5	116	94				Yes	Yes	N
04JD002	51	1	0	0	1.68	2.41	Yes	Yes	0.58	4.71	2.01	2.68	Yes	Yes	(1) 0	6	6	-1				No	No				-2.63	-1.65	-2.33	No	No	R
04JF001	22	1	0	0	1.73	2.54	Yes	Yes	0.6	3.38	2.09	2.85	Yes	Yes	(8) 11	11	8	16				Yes	Yes	21	34	25				No	No	N
04JG001	24	1	0	0	1.72	2.52	Yes	Yes	0.21	0.96	2.07	2.62	No	No	(12) 12	12	6	18				Yes	Yes	60	42	31				Yes	Yes	R
05PA006	70	2	0	0	1.67	2.39	Yes	Yes	-0.37	-3.31	-2	-0.65	Yes	Yes	(29) 35	35			1.69	1.96		Yes	Yes				-1.72	-1.65	-2.33	No	Yes	N
05PA012	64	2	0	0	1.67	2.39	Yes	Yes	-0.17	-1.35	-2	-2.68	No	No	(23) 32	32			2.52	1.96	2.57	No	Yes				-0.24	-1.65	-2.33	Yes	Yes	R
05PB009	28	2	0	0	1.71	2.49	Yes	Yes	0.54	3.25	2.08	2.78	Yes	Yes	(12) 14	14	10	20				Yes	Yes	50	61	47				No	Yes	R
05PB014	72	2	0	0	1.67	2.39	Yes	Yes	-0.4	-3.64	-2	-2.65	Yes	Yes	(27) 36	36			2.37	1.96	2.58	No	Yes				-2.77	-1.65	-2.33	No	Yes	N
05PB016	12	2	0	0	1.83	2.82	Yes	Yes	0.42	1.45	2.23	3.17	No	No	(4) 6	6	4	10				Yes	Yes	12						Yes	Yes	N
05PC018	11	2	0	0	1.67	2.39	Yes	Yes	-0.09	-0.72	-2	-2.68	No	No	(24) 31	31			2.09	1.96	2.56	No	Yes				-1.16	-1.65	-2.33	Yes	Yes	R
05PC019	30	2	0	0	1.67	2.38	Yes	Yes	0.06	0.69	1.99	2.64	No	No	(40) 43	43			0.87	1.96	2.58	Yes	Yes				-0.23	-1.65	-2.33	Yes	Yes	R
05PD015	20	2	0	0	1.74	2.57	Yes	Yes	0.57	2.93	2.1	2.88	Yes	Yes	(2) 0	4	4	-1				No	Yes	30	27	19				Yes	Yes	N
05PD017	20	2	0	0	1.74	2.57	Yes	Yes	0.2	0.82	2.1	2.88	No	No	(1) 0	0	1	12				Yes	Yes	50	27	19				Yes	Yes	N
05PD023	19	2	0	0	1.75	2.56	Yes	Yes	0.38	1.67	2.11	2.9	No	No	(1) 0	1	1	13				Yes	Yes	40	24	16				Yes	Yes	N
05PD028	12	2	0	0	1.83	2.82	Yes	Yes	0.81	4.3	2.23	3.17	Yes	Yes	(4) 6	6	4	10				Yes	Yes	4						No	Yes	R
05QA001	60	2	0	0	1.67	2.4	Yes	Yes	-0.11	-0.64	-2	-2.86	No	No	(23) 30	30			2.08	1.96	2.58	No	Yes				-1.17	-1.65	-2.33	Yes	Yes	N
05QA002	70	2	0	0	1.67	2.39	Yes	Yes	-0.19	-1.63	-2	-2.85	No	No					2.65	1.96	2.58	No	No				-1.38	-1.65	-2.33	Yes	Yes	N
05QA004	30	2	0	0	1.7	2.47	Yes	Yes	0.42	2.48	2.05	2.76	Yes	No	(8) 15	15	11	21				No	Yes	29	72	56				No	No	R
05QC001	29	2	0	0	1.71	2.48	Yes	Yes	0.35	1.92	2.05	2.77	No	No	(12) 14	14	10	20				Yes	Yes	53	68	51				No	Yes	R
05QC003	21	2	0	0	1.73	2.55	Yes	Yes	0.81	3.34	2.09	2.86	Yes	Yes	(8) 10	10	7	15				No	Yes	26	31	22				No	Yes	N
05QD003	27	2	0	0	1.71	2.49	Yes	Yes	0.24	1.26	2.06	2.79	No	No	(13) 13	13	9	19				Yes	Yes	54	56	43				No	Yes	N
05QD006	28	2	0	0	1.69	2.44	Yes	Yes	0.31	1.98	2.03	2.72	No	No	(13) 19	19	14	28				No	Yes	105	123	101				No	Yes	R
05QD016	21	2	0	0	1.73	2.55	Yes	Yes	0.28	1.17	2.09	2.88	No	No	(6) 10	10	7	15				Yes	Yes	35	31	22				Yes	Yes	R
05QE006	49	2	0	0	1.68	2.41	Yes	Yes	0.2	1.41	2.01	2.69	No	No					2.04	1.96	2.58	No	Yes				-0.28	-1.65	-2.33	Yes	Yes	R
05QE007	35	2	0	0	1.69	2.45	Yes	Yes	0.314	1.9	2.04	2.74	No	No	(16) 17	17	12	24				Yes	Yes	74	102	62				No	No	R
05QE008	21	2	0	0	1.73	2.55	Yes	Yes	0.72	4.57	2.09	2.86	Yes	Yes	(8) 10	10	7	15				Yes	Yes	18	32	22				No	No	N
05QE009	31	2	0	0	1.7	2.47	Yes	Yes	0.37	2.16	2.05	2.76	Yes	No	(11) 15	15	11	21				Yes	Yes	50.5	77	61				No	No	N
05RC001	11	2	0	0	1.86	2.9	Yes	Yes	0.26	0.79	2.26	3.25	No	No	(7) 5	6	3	9				Yes	Yes	14						Yes	Yes	N

Yes – Significant, Null Hypothesis Rejected

STATISTICAL TEST RESULTS

NORTHEASTERN REGION (1990)

Station Number	# of Years	Region Code	Spearman Independence: Rank Order	T	Critical T 5%	Critical T 1%	Indicator 5%	Indicator 1%	Spearman Trend: Rank Order	T	Critical T 5%	Critical T 1%	Indicator 5%	Indicator 1%	Run Test For Randomness: Run # N1	N2	Range 5% Low	Range 5% High	Zm	Critical Zm 5%	Critical Zm 1%	Indicator 5%	Indicator 1%	Mann-Whitney For Homogeneity: U	Critical 5%	Critical 1%	Zm	Critical Zm 5%	Critical Zm 1%	Indicator 5%	Indicator 1%	R/N Code
02BD002	70	3	0	0	1.67	2.39	Yes	Yes	-0.56	-5.59	-2	-2.65	Yes	Yes	(18) 35	35			4.33	1.96	2.58	No	No				-4.36	-1.65	-2.33	No	No	R
02BE002	56	3	0	0	1.68	2.4	Yes	Yes	-0.32	-2.48	-2.01	-2.67	Yes	No					3.85	1.96	2.58	No	No				-2	-1.65	-2.33	No	No	R
02BF001	24	3	0	0	1.72	2.52	Yes	Yes	0.3	1.46	2.07	2.82	No	No	(8) 18	18	8	18				Yes	Yes	62.5	42	31				Yes	Yes	N
02BF002	24	3	0	0	7.72	2.52	Yes	Yes	0.3	1.49	2.07	2.82	No	No	(8) 12	12	8	18				Yes	Yes	64.5	42	31				Yes	Yes	N
02BF004	12	3	0	0	1.83	2.82	Yes	Yes	0.66	2.79	2.23	3.17	Yes	No	(4) 6	6	4	10				Yes	Yes	9.5						Yes	Yes	N
02BF005	0 3	3	0	0	1.86	2.9	Yes	Yes	0.32	1	2.26	3.25	No	No	(4) 4	5	3	8				Yes	Yes	13						Yes	Yes	N
02BF006	12	3	0	0	1.83	2.82	Yes	Yes	0.68	2.92	2.23	3.17	Yes	No	(4) 5	5						Yes	Yes	10.5						Yes	Yes	N
02BF007	10	3	0	0	1.9	3	Yes	Yes	0.18	0.51	2.31	3.36	No	No	(2) 0	3	3	-1				No	No	10						Yes	Yes	N
02BF008	11	3	0	0	1.86	2.9	Yes	Yes	0.403	1.32	2.26	3.25	No	No	(2) 0	4	4	-1				No	No	13						Yes	Yes	N
02BF009	10	3	0	0	1.9	3	Yes	Yes	0.261	0.77	2.31	3.36	No	No	(1) 0	0	1	12				Yes	Yes	12.5						Yes	Yes	N
02CA001	118	3	0	0	1.66	2.36	Yes	Yes	-0.01	-0.14	-1.98	-2.62	No	No					5.12	1.96	2.58	No	No				-1.37	-1.65	-2.33	Yes	Yes	R
02CA002	20	3	0	0	1.74	2.57	Yes	Yes	0.22	0.95	2.1	2.88	No	No	(7) 9	9	6	14				Yes	Yes	36.5	27	19				Yes	Yes	N
02CB001	40	3	0	0	1.69	2.43	Yes	Yes	0.46	3.19	2.03	2.71	Yes	Yes	(12) 20	20	15	27				No	No	92	138	114				No	No	R
02CB003	11	3	0	0	1.86	2.9	Yes	Yes	0.51	1.77	2.26	3.25	No	No	(7) 5	5	3	9				Yes	Yes	5						No	No	N
02CC007	41	3	0	0	1.69	2.43	Yes	Yes	0.07	0.44	2.02	2.71	No	No	(14) 20	20	15	27				No	No				-0.77	-1.65	-2.33	Yes	Yes	R
02CC008	40	3	0	0	1.69	2.43	Yes	Yes	-0.03	-0.19	-2.05	-2.71	No	No	(11) 20	20	15	27				Yes	Yes	200	138	114				Yes	Yes	R
02CC009	31	3	0	0	1.7	2.47	Yes	Yes	0.19	1.06	2.05	2.76	No	No	(10) 15	15	11	21				Yes	Yes	86	77	61				Yes	Yes	R
02CC010	11	3	0	0	1.86	2.9	Yes	Yes	0.26	0.82	2.28	3.25	No	No	(7) 5	5	3	9				Yes	Yes	13						Yes	Yes	R
02CD001	25	3	0	0	1.72	2.51	Yes	Yes	0.28	1.39	2.07	2.81	No	No	(8) 12	12	8	18				Yes	Yes	75	47	35				Yes	Yes	N
02CD002	14	3	0	0	1.8	2.72	Yes	Yes	0.31	1.12	2.18	3.06	No	No	(7) 7	7	4	12				Yes	Yes	21.5						Yes	Yes	R
02CD003	14	3	0	0	1.8	2.72	Yes	Yes	0.42	1.6	2.18	3.06	No	No	(7) 7	7	4	12				Yes	Yes	20						Yes	Yes	R
02CD004	22	3	0	0	1.73	2.54	Yes	Yes	0.23	1.05	2.09	2.85	No	No	(8) 11	11	8	16				Yes	Yes	55	34	25				Yes	Yes	R
02CD008	23	3	0	0	1.73	2.53	Yes	Yes	0.22	1.03	2.08	2.83	No	No	(11) 11	11	8	16				Yes	Yes	56	38	28				Yes	Yes	N
02CE001	44	3	0	0	1.68	2.42	Yes	Yes	0.36	2.52	2.02	2.7	Yes	No	(19) 22	22			1.22	1.96		Yes	Yes				-1.81	-1.65	-2.33	No	Yes	R
02CE002	76	3	0	0	1.67	2.38	Yes	Yes	0.04	0.34	2	2.65	No	No	(33) 38	38			1.39	1.96		Yes	Yes				-0.48	-1.65	-2.33	Yes	Yes	R
02CE004	71	3	0	0	1.67	2.39	Yes	Yes	0.34	3	2	2.65	Yes	Yes					2.65	1.96	2.58	No	No				-3.14	-1.65	2.33	No	No	R
02CF005	32	3	0	0	1.7	2.46	Yes	Yes	0.66	5.12	2.04	2.75	Yes	Yes	(7) 14	15	10	21				No		15	83	66				No	No	R
02CF007	31	3	0	0	1.7	2.47	Yes	Yes	-0.2	-1.08	-2.05	-2.76	No	No	(13) 14	14	10	20				Yes	Yes	101	77	61				Yes	Yes	N
02CF008	30	3	0	0	1.7	2.47	Yes	Yes	0.64	4.39	2.05	2.76	Yes	Yes	(6) 13	14	10	19				No		8	72	56				No	No	N
02CF009	32	3	0	0	1.7	2.46	Yes	Yes	0.56	3.72	2.04	2.75	Yes	Yes	(8) 11	14	9	18				No		61.5	83	66				No	No	R
02CF010	15	3	0	0	1.78	2.68	Yes	Yes	-0.03	-0.09	-2.16	-3.01	No	No	(7) 7	7	4	12				Yes	Yes	26						Yes	Yes	R
02CF011	20	3	0	0	1.74	2.57	Yes	Yes	0.5	2.42	2.1	2.88	Yes	No	(12) 10	10	7	15				Yes	Yes	22.5	27	19				No	Yes	R
02CF012	14	3	0	0	1.8	2.72	Yes	Yes	0.02	0.08	2.18	3.06	No	No	(7) 7	7	4	12				Yes	Yes	22.5						Yes	Yes	N
02CF013	10	3	0	0	1.9	3	Yes	Yes	-0.06	-0.17	-2.31	-3.36	No	No	(4) 3	4	1	-1				No	No	10						Yes	Yes	N
02DB005	39	3	0	0	1.69	2.44	Yes	Yes	0.61	4.69	2.03	2.72	Yes	Yes	(12) 19	19	14	26				No	No	59	120	107				No	No	R
02DB007	11	3	0	0	1.86	2.9	Yes	Yes	0.18	0.55	2.26	3.25	No	No	(5) 4	5	3	8				Yes	Yes	14						Yes	Yes	N
02DC003	70	3	0	0	1.67	2.39	Yes	Yes	0.07	0.6	2	2.65	No	N0	(22) 35	35			3.37	1.96	2.58	No	No				-0.5	-1.65	-2.33	Yes	Yes	R
02DC007	53	3	0	0	1.68	2.41	Yes	Yes	-0.58	-5.18	-2.01	-2.68	Yes	Yes	(2) 0	7	7	-1				No	No				-2.75	-1.65	-2.33	No	No	N
02DC008	52	3	0	0	1.68	2.41	Yes	Yes	-0.2	-1.46	-2.01	-2.68	No	No	(8) 0	26	1	24				Yes	Yes				-1.38	-1.65	-2.33	Yes	Yes	R
02DD005	47	3	0	0	1.68	2.42	Yes	Yes	0.213	1.46	2.01	2.69	No	No	(18) 23	23			1.79	1.96		Yes	Yes				-1.03	-1.65	-2.33	Yes	Yes	R
02DD008	27	3	0	0	1.71	2.49	Yes	Yes	-0.27	-1.39	-2.06	-2.79	No	No	(12) 12	13	9	18				Yes	Yes	57	56	43				Yes	Yes	N
02DD009	35	3	0	0	1.69	2.45	Yes	Yes	0.401	2.52	-2.04	2.74	Yes	No	(12) 17	17	12	24				Yes	Yes	86	102	82				No	Yes	R
02DD010	30	3	0	0	1.7	2.47	Yes	Yes	-0.23	-1.26	-2.05	-2.76	No	No	(11) 15	15	11	21				Yes	Yes	93.5	72	56				Yes	Yes	R
02DD013	17	3	0	0	1.76	2.62	Yes	Yes	0.4	1.7	2.13	-2.95	No	No	(6) 8	8	5	13				Yes	Yes	27.5	18	11				Yes	Yes	N
02DD015	17	3	0	0	1.76	2.62	Yes	Yes	0.21	0.83	2.13	2.95	No	N0	(8) 8	8	5	13				Yes	Yes	29	18	11				Yes	Yes	N

TABLE 3.1(b)
STATISTICAL TEST RESULTS
NORTHEASTERN REGION (1990)

Station	# of	Region	Spearmen Independence						Spearman Trend						Run Test For Randomness									Mam - Whitney For Homogeneity								R/N
			Rank	T	Critical T		Indicator		Rank	T	Critical T		Indicator		Run #		Range 5%		Zm	Critical Zm		Indicator		U	Critical		Zm	Critical Zm		Indicator		
Number	Years	Code	Order		5%	1%	5%	1%	Order		5%	1%	5%	1%	N1	N2	Low	High		5%	1%	5%	1%		5%	1%		5%	1%	5%	1%	Code
02EA005	76	3	0	0	1.67	2.38	Yes	Yes	-0.06	-0.48	-2	-2.65	No	No	(33) 36	37			1.06	1.96		Yes	Yes				-0.66	-1.65	-2.33	Yes	Yes	N
02EA006	76	3	0	0	1.67	2.38	Yes	Yes	0.34	3.14	1.99	2.65	Yes	Yes	(32) 27	37			1.41	1.96		Yes	Yes				-2.66	-1.65	-2.33	No	No	R
02EA010	23	3	0	0	1.73	2.53	Yes	Yes	0.42	2.12	2.08	2.63	Yes	No	(11) 11	11	8	16				Yes	Yes	48.5	38	28				Yes	Yes	N
02EA011	18	3	0	0	1.75	2.6	Yes	Yes	0.33	1.4	2.12	2.92	No	No	(6) 9	9	6	14				Yes	yes	23	21	14				Yes	Yes	R
02EA013	11	3	0	0	1.86	2.9	Yes	Yes	-0.67	-2.72	2.26	-3.25	Yes	No	(4) 5	5	3	9				yes	Yes	7						Yes	Yes	N
02EB014	10	3	0	0	1.9	3	Yes	Yes	0.75	3.16	2.31	3.36	Yes	No	(4) 5	5	3	9				Yes	Yes	4						No	Yes	R
02JC006	23	3	0	0	1.73	2.53	Yes	Yes	-0.31	-1.51	-2.08	-2.83	No	No	(12) 11	11	8	16				Yes	Yes	46	38	26				Yes	Yes	N
02JD010	19	3	0	0	1.75	2.58	Yes	Yes	0.31	1.34	2.11	2.9	No	No	(8) 9	9	6	14				Yes	Yes	30	24	16				Yes	Yes	R
02JD011	45	3	0	0	1.68	2.42	Yes	Yes	0.34	2.4	2.02	2.7	Yes	No	(3) 0	3	3	-1				No	Yes				-1.81	-1.65	-2.33	No	Yes	R
02JE012	39	3	0	0	1.7	2.44	Yes	Yes	0.24	1.53	2.03	2.72	No	No	(21) 19	19	14	26				Yes	Yes	127	120	107				Yes	Yes	R
02JE018	12	3	0	0	1.83	2.82	Yes	Yes	0.37	1.26	2.23	3.17	No	No	(6) 6	6	4	10				Yes	Yes	15.5						Yes	Yes	N
02JE019	19	3	0	0	1.75	2.58	Yes	Yes	-0.03	-0.13	-2.11	-2.9	No	no	(9) 9	9	6	14				Yes	Yes	42.5	24	16				Yes	Yes	R
02JE020	20	3	0	0	1.74	2.57	Yes	Yes	0.22	0.96	2.1	2.68	No	No	(9) 10	10	7	15				Yes	Yes	36.5	27	19				Yes	Yes	R
02JE021	45	3	0	0	1.68	2.42	Yes	Yes	0.27	1.82	2.02	2.7	No	No	(3) 0	4	4	-1				No	No				-1.15	-1.65	-2.33	Yes	Yes	R
04KA001	21	1	0	0	1.73	2.55	Yes	Yes	0.32	1.48	2.09	2.86	No	No	(10) 9	10	6	15				Yes	Yes	53.5	31	22				Yes	Yes	N
04LA002	22	1	0	0	1.73	2.54	Yes	Yes	0.26	1.2	2.09	2.85	No	No	(11) 11	11	8	16				Yes	Yes	58	34	25				Yes	Yes	R
04LD001	70	1	0	0	1.67	2.39	Yes	Yes	-0.33	-2.88	-2	-2.65	Yes	Yes					3.37	1.96	2.58	No	No				-2.12	-1.65	-2.33	No	Yes	R
04LF001	73	1	0	0	1.67	2.39	Yes	Yes	0.1	0.87	2	2.65	No	No					0.48	1.96	2.56	Yes	Yes				-0.33	-1.65	-2.33	Yes	Yes	R
04LG002	24	1	0	0	1.72	2.52	Yes	Yes	0.53	2.92	2.07	2.82	Yes	Yes	(12) 12	12	8	18				Yes	Yes	26	42	31				No	No	R
04LJ001	71	1	0	0	1.67	2.39	Yes	Yes	-0.00	-0.01	-1.99	-2.65	No	No					0.48	1.96	2.58	Yes	Yes				-0.22	-1.65	-2.33	Yes	Yes	N
04LM001	19	1	0	0	1.75	2.58	Yes	Yes	-0.06	-0.23	-2.11	-2.9	No	No	(7) 9	9	6	14				Yes	Yes	41	24	16				Yes	Yes	N
04MB003	37	1	0	0	1.69	2.44	Yes	Yes	0.3	1.84	2.038	2.73	No	No	(1) 0	1	1	13				Yes	Yes	162	116	94				Yes	Yes	R
04MC001	36	1	0	0	1.67	2.39	Yes	Yes	-0.6	-6.25	-2	-2.65	Yes	Yes					4.33	1.96	2.58	No	No				-4.25	-1.65	-2.33	No	No	R
04MD002	53	1	0	0	1.66	2.41	Yes	Yes	0.48	3.91	2.01	2.68	Yes	Yes	(7) 0	12	10	20				No	No				-2.55	-1.65	-2.33	No	No	R
04MD004	14	1	0	0	1.8	2.72	Yes	Yes	-0.8	-4.56	-2.18	-3.06	Yes	Yes	(5) 7	7	4	12				Yes	Yes	1						No	No	N
04ME002	59	1	0	0	1.67	2.4	Yes	Yes	-0.02	-0.12	-2	-2.67	No	No	(30) 29	29			0	1.98	2.58	Yes	Yes				-0.17	-1.65	-2.33	Yes	Yes	R
04ME003	32	1	0	0	1.7	2.47	Yes	Yes	0.02	0.1	2.04	2.75	No	No	(15) 16	16	12	22				Yes	Yes	118	63	62				Yes	Yes	R
04ME004	30	1	0	0	1.7	2.47	Yes	Yes	0.35	1.94	2.05	2.76	No	No	(11) 15	15	11	21				Yes	Yes	60	72	56				No	Yes	R
04MF001	25	1	0	0	1.72	2.51	Yes	Yes	0.4	2.07	2.07	2.81	Yes	No	(8) 12	12	8	16				Yes	Yes	38	47	35				No	Yes	N

Null Hypothesis

Independence:	The correlation is one (i e yes indicates independence)
Trend:	The serial lag-one correlation is zero (i e yes indicates trend)
Randomness	The data is not random (i e yes indicates the data is random)
Homogeneity	There is location difference between the two time periods (i e. yes indicates homogeneity)

zero flows, so that frequency analysis could not be performed and, therefore, these stations are screened out of the analysis.

Low flow characteristics were determined for flow records up to 1990 for the 93 selected stations using L-moment methods. The application of L-moments for low flows is new in Ontario and hence the results were compared to standard methods. The results of the low flow frequency analysis compare very well with the previous low flow characteristics for selected recurrent intervals (see Figure 3.1 and 3.2 and Section 3.3.3 for details). Relevant physiographic and meteorological characteristics were also determined as discussed in Section 3.4.

3.2 Trend Analysis

3.2.1 Introduction

Some previous work (Low Flow Characteristics in Ontario, Cumming Cockburn Limited, 1988) indicated that there might be trend in some of the low flow series for stations in the Northwestern and Northeastern Regions. A more detailed analysis was undertaken to determine if trend is present in these low flow statistics. If trend was found to be present, it was postulated that some correction method should be applied to those stations prior to developing a regionalization method. This might include the following options:

1. Neglecting the trend if it is weak or insignificant or if it is considered to be part of a recurring cycle.

2. Another approach would be to simply screen out all of the stations that show trend. However, this could result in a significant loss of useful information, especially if the regionalization results are unaffected.

3. Finally an approach could be developed in an effort to remove the trend to adjust the low flow series, then the "detrended" data could be used in the regionalization analysis. (however, this might require a means of accounting for the trend in practical applications if the effects on low flow predictions are significant).

The following sections summarize trend analysis and results (3.2.2, 3.2.3) and Appendix A describes in more detail the methods utilized.

TABLE 3.2(a)
LOW FLOW CHARACTERISTICS FOR STATIONS WITH "SIGNIFICANT TREND" ACCORDING TO MANN-KENDALL TEST (1990)
NORTHWESTERN REGION

Station #	Drianage Area (km^2)	Period of Record (year - year)	Number of Years	Reg* Code	7Q Mean (m^3/s)	7Q Max (m^3/s)	7Q Min (m^3/s)	Rate of** Change ($m^3/s/Year$)
02AB004	3760	1923-1990	68	R	1.81	20.43	0	-0.0079
02AB013	526	1951-1990	40	R	0.23	2.99	0	-0.0093
02AD008	24600	1950-1990	41	R	222.45	356.57	92.34	-1.72
02BB002	1980	1967-1990	24	N	3.965	8.62	0.07	-0.066
04CA002	36500	1965-1990	25	N	75.9	282.43	33.7	-1.511
04CB001	10800	1967-1990	24	N	43.58	64.83	25.86	-0.518
04DA001	5960	1966-1990	25	N	9.88	24.39	5.22	-0.142
04DC001	50000	1965-1990	25	N	84.05	373.71	58.43	-1.253
04FA001	9010	1966-1990	25	R	16.91	37.39	8.5	-0.2047
04FA003	4900	1966-1990	25	N	6.55	10.93	2.8	-0.0896
04FB001	24200	1965-1990	24	N	48.11	74.11	15.43	-1.2077
04GD001	32400	1966-1990	22	R	55.98	88.6	27.71	-1.041
04JD002	4270	1939-1990	51	R	0.06	0.87	0	-0.0023
04JF001	5360	1968-1990	22	N	13.53	38.03	6.13	-0.521
05PA006	13400	1921-1990	70	N	35.54	71.03	15.1	0.1121
05PB009	5880	1963-1990	28	R	12.94	34.33	0	-0.4112
05PB014	4870	1914-1990	72	N	11.86	22.64	1.45	0.0788
05PD026	744	1979-1990	12	R	0.46	0.95	0.01	-0.0439
05PE006	unknown	1907-1990	84	R	55.17	93.91	0	0.5765
05QA004	4450	1961-1990	30	N	13.4	21.86	4.51	-0.0999
05QC003	2370	1970-1990	21	N	7.93	14.57	1.92	-0.213
05QE008	1690	1970-1990	21	N	4.39	7.97	1.73	-0.1899

*R - Regulated Flow
N - Natural Flow
** - By LWRS - see Appendix A

TABLE 3.2(b)
LOW FLOW CHARACTERISTICS FOR STATIONS WITH "SIGNIFICANT TREND" ACCORDING TO MANN-KENDALL TEST (1990) NORTHEASTERN REGION

Station #	Drianage Area (km^2)	Period of Record (year - year)	Number of Years	Reg* Code	7Q Mean (m^3/s)	7Q Max (m^3/s)	7Q Min (m^3/s)	Rate of** Change ($m^3/s/Year$)
02BD002	5130	1920-1990	71	R	30.25	61.01	5.39	0.179
02BE002	2880	1935-1990	56	R	16.7	30.67	0	0.093
02BF004	51.5	1979-1990	12	N	0.07	0.29	0.02	-0.003
02BF006	8.64	1979-1990	12	N	0.02	0.09	0	-0.001
02CB001	4040	1946-1990	40	R	7.77	23.03	0.39	-0.123
02CE001	11400	1915-1990	44	R	43.95	72.74	17.57	-0.006
02CE004	6800	1920-1990	71	R	31.35	54.17	0	-0.078
02CF005	89.1	1968-1990	32	R	0.164	0.32	0.08	-0.003
02CF008	155	1960-1990	30	N	0.744	3.34	0.05	-0.033
02CF009	21.5	1959-1990	32	R	0.02	0.09	0	-0.0005
02CF011	704	1970-1990	20	N	2.414	3.89	1.01	-0.033
02DB005	3130	1952-1990	39	R	11.82	29.36	2.52	-0.176
02DC007	1360	1938-1990	53	R	0.38	3.79	0	0.008
02DD009	316	1956-1990	35	R	1.57	2.91	0.22	-0.012
02DD016	unknown	1980-1990	11	R	4.39	14.3	0.71	-0.375
02EA006	650	1915-1990	76	N	1.97	5.18	0.12	-0.009
02EB014	601	1981-1990	10	R	1.493	4.33	0.52	-0.11
04LD001	1190	1920-1990	70	R	30.01	53.73	7.85	0.105
04LG002	60100	1959-1982	24	R	164.98	241	74.03	-1.75
04MC001	13300	1920-1990	71	R	78.55	153.43	35.13	0.55
04MD002	2870	1938-1990	53	R	0.19	1.86	0	-0.0024
04MD004	401	1977-1990	14	N	0.58	0.89	0.27	0.0273
04ME004	23400	1961-1990	30	R	159.1	243.71	96.23	-1.029

*R - Regulated Flow
N - Natural Flow
** - By LWRS - see Appendix A

3.2.2 Summary of Trend Analysis

Statistical Tests

The Mann-Kendall test and Spearman test (described in Appendix A) were used to check for trend in minimum flow series at each station. The results of the Spearman Test for Trend are summarized in Table 3.1. The results of the Mann-Kendall test for trend are summarized in Table 3.2, which also includes the "rate of change" as determined from the Locally Weighted Regression Smooth (see Section 3.2.3 and Appendix A).

The testing was undertaken for two data sets, the first data set has a data record from which 7 day average low flows were extracted for each station up to 1986. Part way through the study, an additional four years of data became available. The data base was then updated to 1990, and the trend tests were re-applied. A comparison of the test result was surprising since it revealed significant differences in findings regarding trend at numerous stations.

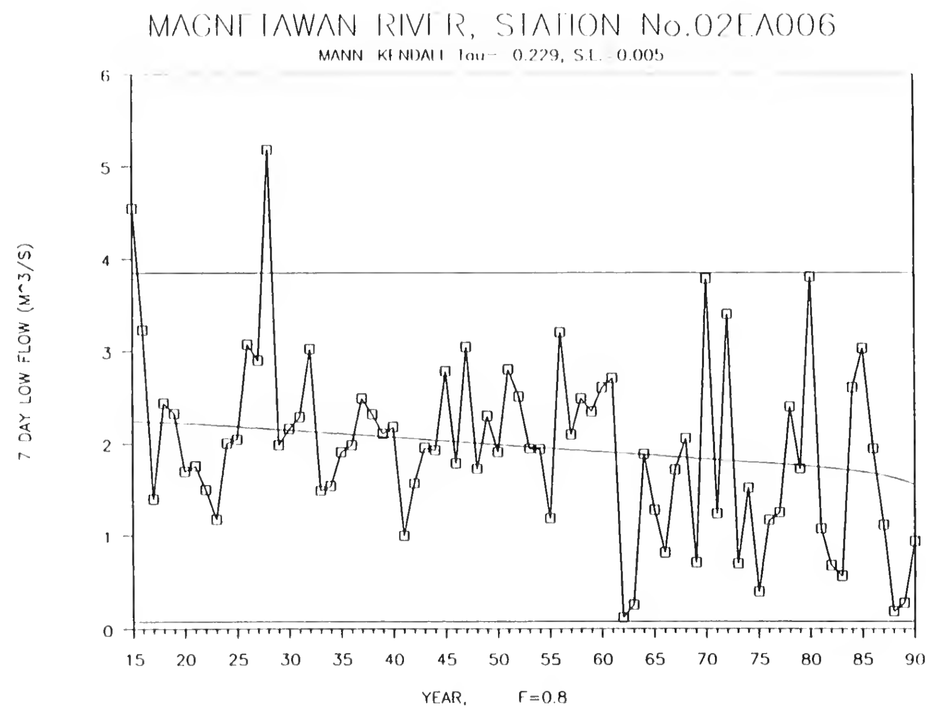
a) The Old Data Base

Reference to Table 3.3 summarizes the frequency of trend detection. A higher percentage of stations were found to exhibit trend in the Northwestern Region compared to the Northeastern Region.

The locally weighted regression smooth technique was applied to those station records where the statistical tests indicated the presence of trend (see Section 3.2.3). (Typical results are presented in Figure 3.3 with additional graphs for other stations given in Appendix A.)

The statistical tests are compared in Appendix A, and it is generally concluded that the two tests agree with each other in most cases.

Note that the signs of Mann-Kendall's tau and Spearman's rho are different. That is, when the Mann-Kendall test detected an upward trend, the sign of tau is positive, whereas the rho of Spearman's test will be negative (see Appendix A). If it is assumed that the trends (if they actually exist) can be characterized as monotonic then based on the data sets extending to 1986 there is approximately a 50% split between stations exhibiting increasing and decreasing trend. Spatial analysis did not identify any significant clusters of stations which might reveal regional characteristics (in this case no trend adjustment is considered to be warranted).



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	EXAMPLE OF TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE 3.3

TABLE 3.3(a)

COMPARISON OF RESULTS FOR TREND TESTING (-1986)

(Percentage of Stations)

Significant Level	Northwestern				Northeastern			
	Mann-Kendall		Spearman		Mann-Kendall		Spearman	
	Yes	No	Yes	No	Yes	No	Yes	No
5%	17	83	21	79	28	72	33	67
1%	6	94	10	90	17	83	18	82

Yes - Trend present
No - No trend present

TABLE 3.3(b)

COMPARISON OF RESULTS FOR TREND TESTING (-1990)

(Percentage of Stations)

Significant Level	Northwestern				Northeastern			
	Mann-Kendall		Spearman		Mann-Kendall		Spearman	
	Yes	No	Yes	No	Yes	No	Yes	No
5%	28	72	34	66	29	71	34	66
1%	22	78	25	75	14	86	18	82

Yes - Trend present
No - No trend present

b) Revised Data Base

The data base was then updated to 1990 and the tests for trend were re-applied (see Appendix A). The locally weighted regression smooth technique was also applied to data records with significant trend for the new data set (see Appendix A). Appendix A compares the trend analysis between the two data sets. The updated analysis suggest that approximately 75% of the stations show significant trend, compared to 50% for the old data base. While the trend statistics indicate decreasing low flows at many locations, some data also show an increase in low flows with time.

The additional data resulted in a considerable change in results between the previous data set and the updated data set. The overall results are summarized in Tables 3.3(a) and 3.3(b) which indicate that stations in the Northwestern Region as a group show slightly more trend than the shorter data set. However, for specific stations, the change in record length significantly affected the statistical tests.

In the Northwestern region, twelve (12) stations show downward trend for the new data set, while there was no trend at these stations for the old data set. Two (2) stations that show upward trend previously did not have trend. In the Northeastern region, six (6) stations were found to have downward trend for the longer flow records, whereas these stations previously passed the trend tests when the shorter data set was used. There are also three (3) stations which indicated upward trend previously, but which did not show trend for the new data records. One (1) station was found to have an upward trend where no trend was detected with the old data set. The downward trend detected for one station was not evident when the record length was extended. These inconsistencies suggest that the statistical tests are vary sensitive to record length and/or some elements of change in low flows on a cyclic basis may be responsible.

With reference to Appendix A it is noted that it is very likely that for some of the stations the apparent trend may be due to regulated flow conditions. For some of those regulated stations when a trend is being detected, the data are also non-random and non-homogeneous. This shift of direction may suggest that the trends are not monotonic and we have been just experiencing a drought portion of a cycle. Here, no homogeneity means that if the data is split into the two subsets according to time span, the two subsets are significantly different from each other. In other words, the data comes from two populations in two time periods. It may be possible to explain this due to a change in regulation for these stations. Therefore, those stations showing trend with regulated flows should be screened out of the data base.

It concluded that the statistical trend indicators are sensitive to the record length. As discussed above, when an additional four years data is included, the trend indicated for many stations is inconsistent. This implies that the possibility of long term cyclic fluctuations in low flow time series should be examined over a longer time base in order to judge whether or not a trend really exists.

In general it was found (see Appendix A) that the Spearman trend test is a more strict statistical condition, compared to Mann and Kendall. It is also noted that longer hydrologic data sets are required in order to obtain more conclusive results in regard to trend analysis for low flow time series.

3.2.3 Trend Adjustment

A method was developed to adjust trend in low flow time series, (see Appendix A) and was applied to these stations identified by the statistical tests as having "significant trend". The Robust Locally Weighted Regression Smooth results were used to obtain the total change over the record period. Table 3.2 presents the rate of change per year for the flow records. A negative rate of change indicates that the low flow records show a downward trend and positive signs imply that the time series have an upward trend. The data set was adjusted and the statistical tests and analysis of low flow characteristics were re-calculated. Table A.3 compares the results of the Mann-kendall test for the low flow time series before and after applying these procedures and it is clear that the trend was removed from the records.

To evaluate the impacts of trend adjustment to the low flow characteristics, that is whether or not the low flow characteristics changed significantly, the frequency analysis procedures were applied to the time series after adjustment. Table A.4 gives the results of low flow frequency analysis for the time series before and after applying these procedures. In general, no major differences for the low flow characteristics are evident from Table A.3. This implies that it is not necessary to make a trend adjustment in the analysis of low flow characteristics for the purpose of regionalization. (On the other hand slightly more conservative estimates of $7Q_{20}$ are produced from the unadjusted data set.)

3.2.4 Conclusions and Recommendations

The following summarizes the main conclusions and recommendations concerning the low flow trend analysis.

1. In total, forty-five (45) stations were identified to have trend in the low flow records. Among these, twenty-six (26) stations are regulated. For the remaining stations with natural flows, only three have a significant record length (over 70 years of record), the other stations having up to only 30 years record, which is relatively short. The trend testing results were found to be sensitive to the length of record as discussed in Section 3.2.2. Thus, it is concluded that the trend component for short term stations may not be real. More detailed study should be undertaken to confirm whether the trend is real for stations with short record lengths.

2. There were found to be eighteen (18) more stations which have some downward trend for the new data set (to 1990) compared with the previous Mann-Kendall testing results for the old data set (to 1986). However, one third of these stations have a short record length, having been added to the data base as a consequence of the increase in the length of available record (i.e. from 1986 to 1990). Overall, about 82% of the stations tested showed no evidence of trend at the 1% level of significance (Table 3.3.b).

3. Five (5) stations which showed upward trend, for the old data set (-1986), do not show significant trend for the new data set (-1990).

4. One (1) station that showed downward trend for the shorter data set does not show trend for the longer data set.

5. One (1) station for the new data set shows upward trend (-1990) where no trend was previously detected (-1986).

6. For those stations with trend, the effect can be removed as described in Appendix A. However, it was found that there are no major impacts on the regionalization of low flow characteristics by making this adjustment since it was found that differences in the low flow frequency characteristics were small.

7. A cause and effect relationship for trend (if it actually exists) has not been established. It is possible that recent hydrologic fluctuations of a cyclic nature may be responsible for the test results at some stations. Other factors, such as climate change, may also be important. Additional research is required to investigate such relationships.

8. Ongoing collection of discharge measurements at hydrometric stations should be encouraged. Long term measurements are required for further analysis of trend and low flow characteristics.

3.3 Low Flow Characteristics

3.3.1 Data Base

As discussed in Section 3.1, there are one hundred and ninety-four (194) stations in the Northwestern and Northeastern regions that were available for the purposes of this investigation. Twenty-one (21) stations were reserved for testing. Ninety-three (93) stations (47 in Northwestern region, 46 in Northeastern region) were analyzed to determine regional low flow characteristics. The remaining 80 stations were screened out for various reasons.

3.3.2 Station Screening

The stations which were not considered to possess a suitable low flow data base for the purposes of this investigation were not included in the regionalization analysis. These stations were excluded for the following reasons:

i) Multiple Stations

It was determined that large river systems may have several streamflow gauges at several locations along the main channel. The use of all such highly correlated data could adversely bias the development of regionalization methods. Therefore, only representative gauges for such streams were retained for further analysis. A few of the multiple stations were used for testing the developed techniques.

ii) Heavily Regulated

Low flows on heavily regulated streams are affected through the use of reservoirs for low flow augmentation. Since the main focus of this study is to produce a method for investigating low flows for ungauged watersheds, stations indicating a high degree of regulation were excluded from the data base. The Water Survey of Canada identifies gauges as regulated (R) or natural streams (N), however, the degree of regulation is not quantified for these regions. Of the 194 stations, 91 were identified as "regulated" to some degree. Therefore, objective screening of the "regulated" stations was undertaken (13 stations were removed). The remaining "regulated" stations were retained and assigned a regulatory code representing regulation or non-regulation. Subsequent simple correlation analysis (between the regulatory codes and the low flow statistics) confirmed that these stations could be retained in the data set due to insignificant levels of correlation. Future studies should investigate and quantify the degree of regulation and possible techniques to de-regulate low flow series.

iii) Statistical Tests

Statistical data analysis tests were undertaken as described in detail in the Regional Analysis of Low Flow Characteristics for Northwestern and Northeastern Regions by Cumming Cockburn Limited (1990). Procedures for applying various statistical tests were recently made available as part of the LFA low flow package (Pilon and Jackson, 1987). The relevant test results are summarized in Table 3.1.

In general, it was found that a significant number of stations "failed" the non-parametric tests. Therefore, taken over the entire data base, application of these tests has indicated that the available data base of extreme low flows may exhibit some trend, dependence and non-homogeneity with some possibility of non-random characteristics (see Table 3.1).

The data was further analyzed by subdivision of the available data set according to length of record (ie. $\geq$20 years and <20 years) and according to regulation code. However, it was found that neither the length of record nor the possible effects of regulation could account for the conclusions of the test results. One explanation could be that the available record lengths are too short to permit reasonable application and interpretation of these non-parametric test results. Another explanation could relate to seasonal effects on low flows, for example low flows in the winter and summer may belong to distinct populations. A stronger possibility is that the available low flow data

sets do exhibit trend and non-random characteristics, which could possibly be attributed to slow cyclic change in groundwater levels or to climatic trends. Additional testing was beyond the scope of the current investigations. However, further studies are recommended since these results may call into question the basic assumptions underlying application of the extreme value analysis technique for analysis of low flow characteristics.

Only the stations simultaneously failing the statistical screening for trend, randomness and homogeneity were removed from the analysis (19 stations).

iv) Undeterminable Drainage Area

It was found that the drainage areas of some stations are undeterminable for various reasons, such as multiple outlets. In this case, the records could not be used in the regionalization. Therefore, those stations with undeterminable drainage areas were excluded from the analysis (11 stations).

v) Stations exhibiting questionable data characteristics from the graphical review were removed from the analysis (eg. a large number of zero flows, etc. see figures in Appendix A).

3.3.3 Extreme Value Analysis

Moving average low flows (n-day) were determined and extracted for each year of the available data base. Extreme low flows were then determined and extracted for the n-day durations and are available as part of the background files.

An extreme value analysis was then undertaken for each n-day (n = 1, 3, 7, 15, and 30) duration for each of the stations. General low flow statistics of the data base were then calculated (mean, standard deviation and coefficient of skew of the available low flow samples). These general statistics are summarized in Tables 3.4 to 3.7, and indicate that measured low flows in Northern Ontario are higher than other parts of Ontario. This is attributed to the higher number of large watersheds monitored in the North and to climate and physiographic differences.

The frequency analysis of n-day low flows was undertaken using both conventional moments and L-moments. The extreme-value analysis techniques are described in Appendix B.

TABLE 3.4

SUMMARY OF SELECTED LOW FLOW STATISTICS

Region	Number of Stations	n Day Duration	Mean (m^3/s)	Standard Deviation (m^3/s)	Skew	Coefficient of Variation	Mean Value of Number of Years
Ontario	344	7	13.80	4.06	0.75	0.62	28
Northwestern	47	7	31.0	43.9	1.82	0.63	29
Northeastern	46	7	26.1	63.3	6.68	0.64	32
Region One[1]	28	7	45.3	55.1	1.63	0.61	21
Region Two[1]	14	7	44.9	54.5	0.94	0.49	31
Region Three[1]	51	7	14.9	50.1	7.04	0.64	32
Northern Ontario	93	7	28.6	54.4	9.21	0.68	30

See Section 3.5 for a discussion of sub-regions selected for Northern Ontario

TABLE 3.5

SUMMARY OF $7Q_y$
(MEANS AND STANDARD DEVIATION)

Region	Number of Status	Recurrence Interval (Years)							
		2 Year (m^3/s)		5 Year (m^3/s)		10 Year (m^3/s)		20 Year (m^3/s)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Northern	93	24.22	41.71	17.65	31.88	14.86	27.80	12.75	24.96
Northwestern	47	29.85	42.43	20.99	29.93	17.38	25.08	14.45	21.93
Northeastern	46	18.34	40.12	14.16	33.44	12.22	30.16	10.78	27.64
Region One	28	43.70	55.1	33.85	36.09	30.25	32.00	27.70	36.64
Region Two	14	43.20	53.30	26.96	34.40	20.13	26.39	14.50	20.60
Region Three	51	14.31	49.81	10.83	35.1	9.1	35.11	7.46	30.69

TABLE 3.6

SUMMARY OF $7Q_y$
UNIT AREA AVERAGE LOW FLOWS

Region	Number of Stations	Recurrence Interval (Years)							
		2 Year ($l/s/km^2$)		5 Year ($l/s/km^2$)		10 Year ($l/s/km^2$)		20 Year ($l/s/km^2$)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ontario	344	1.91	1.90	1.38	1.39	1.15	1.24	0.99	1.14
Northern Ontario	93	2.49	1.93	1.73	1.67	1.43	1.56	1.22	1.50
Northwestern	47	2.43	2.17	1.73	1.91	1.45	1.82	1.26	1.77
Northeastern	46	2.54	1.63	1.74	1.37	1.4	1.24	1.19	1.15
Region One	28	2.84	2.88	2.27	2.52	2.04	2.39	1.87	2.31
Region Two	14	2.41	0.91	1.42	0.74	1.03	0.62	0.74	0.50
Region Three	51	2.3	1.38	1.53	1.10	1.2	0.96	0.99	0.87

TABLE 3.7

COMPARISON OF MEAN AND S.D. BETWEEN L-MOMENT AND CONVENTIONAL MOMENT METHOD

Region		L-Moment				Conventional Moment			
		$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$
Northern Ontario	Average	21.14	15.64	13.27	11.40	21.59	16.01	13.40	11.46
	S.D.	38.62	29.73	25.72	22.69	39.13	29.84	25.41	22.11
Northwestern	Average	25.41	18.31	15.40	13.09	26.15	19.07	15.81	13.41
	S.D.	39.42	28.94	24.61	21.53	40.50	29.84	24.92	21.40
Northeastern	Average	16.25	12.58	10.82	9.47	16.35	12.51	10.65	9.22
	S.D.	37.08	30.32	26.72	23.80	36.71	29.44	25.68	22.69
Region One	Average	36.43	28.96	25.62	23.18	37.00	29.25	25.59	22.82
	S.D.	50.53	41.11	36.46	32.87	51.12	40.79	35.56	31.48
Region Two	Average	40.88	26.68	20.69	15.45	41.72	27.69	21.09	16.15
	S.D.	49.16	33.75	27.04	21.85	49.74	34.58	27.52	22.40
Region Three	Average	6.58	4.78	3.88	3.32	6.82	4.91	4.05	3.43
	S.D.	12.04	8.81	7.35	6.31	12.42	9.09	7.57	6.47

Note: 1. Conventional Moment data set (-1986); - stations
L-moment data set (-1990); - stations

2. The sub-regions are defined in Section 3.5.

Recent research indicated that conventional moments are not always satisfactory in two respects, they do not always impart easily interpreted information about the shape of a distribution, and estimates of parameters of distribution fitted by the moments are often less accurate than those obtained by other methods such as maximum likelihood.

An alternative to conventional moments is L-moments. Theoretically, L-moments are able to characterize a wide range of distributions than conventional moments. They are less subject to bias in estimation, and they approximate their asymptotic normal distribution more closely. The main advantage of L-moments over conventional moments is that L-moments suffer less from the effects of sampling variability, they are more robust to outliers in the data. Therefore, L-moments were used in the extreme value analysis.

An updated version of LFA program (Hydrology Division, Water Resources Branch, Environment Canada, 1989), which incorporated the extreme value analysis techniques including L-moments described in Appendix B was utilized for undertaking the calculations for the Northwestern and Northeastern Regions of Ontario respectively.

The low flow frequency analysis results for the 7 day duration are summarized in Table B.1 (a) and B.1 (b). Table B.2 presents the low flow characteristics of 1, 3, 15, and 30 days duration (data to 1990). The frequency curves parameters are given in Table B.3. The following points summarize the main findings:

- No significant changes were found between the previous results and the present study. The selected low flow values ($7Q_2$, $7Q_5$, $7Q_{10}$ and $7Q_{20}$) are comparable for most stations, although the extended record results in improved estimates at some stations.

  Two statistical tests (T-test for means and X^2 - test for standard deviation), for comparing the differences of the means and standard deviations calculated both by L-moments and conventional moments methods, were applied and the results shown that no significant differences could be identified between the two sets of results at the 5% or 1% probability levels for Northern Ontario and its sub-regions. However, the L-moment method normally gives more conservative estimations for the low flow characteristics (see Table 3.7). This finding is consistent with Clarke, et al, 1990.

- For some stations, the minimum 7-day low flows in the data set are either equal to zero or too many zero flows exist. Thus, the frequency analysis could not be undertaken and 16 stations were screened out from the data set as previously described (eg. 05PD015, 05PD017, 05PD023 ... etc.).

- From the results of the frequency analysis, it was found that almost all of the station's low flow data sets (except station 04CA004) could be best fitted by the Weibull distribution. This is an indicator of regional homogeneity in the sense of the selected probability distribution. In the case of station 04CA004, the three-parameter lognormal distribution was selected due to the large negative skewness in the available data base.

3.3.4 Summary Maps

Selected low flow characteristics were extracted and summarized on maps for the study area (see Figure 3.1 and 3.2 in pocket). The data shown is for the 7 day duration.

A relational data base management system (RDBMS) was established that contains both Hydex information regarding characteristics of the hydrometric stations (hydrometric station number, period of record, drainage area, regulation code, latitude, longitude, etc.) and low flow statistics (hydrometric station number, $7Q_2$, $7Q_{10}$, $7Q_{20}$, etc.). The Hydex and Low Flow data were stored in separate tables in the RDBMS, with a common column (hydrometric station number) that allows linkage of the two data sets.

The RDBMS data base file was linked to a digital map of the Province available through the Ministry of Natural Resources' Land and Resource Information Branch. Using the hydrometric station's latitude and longitude as reference points permits an automated transferral of tabular data to the digital map. A presentation chart format was created that allows display of specified data from the Low Flow table of the RDBMS (see Figure 3.1). This automated procedure provides flexibility to present any column of data from the RDBMS, and to make efficient updates to the mapping as additional data becomes available.

Providing a GIS/RDBMS link for the low flow data base enables an efficient means for undertaking spatial analysis of low flow characteristics. For example, preliminary isolines of $7Q_2$ and $7Q_{20}$ unit low flows were produced for Northeastern and Northwestern regions using data in the Low Flow table of the RDBMS.

By combining the longitude (x) and latitude (y) of the Hydex Table, with the $7Q_2$ unit low flow (z) (or $7Q_{20}$ unit low flow) of the Low Flow Table, a series of (x, y, z) coordinates were produced. This data was subsequently interpolated using a third party software contouring package, and imported into the GIS for presentation. Isolines can automatically be created for any (x, y, z) series of data in the RDBMS, and overlayed on other GIS data bases. An example preliminary computer generated isoline map is included in Appendix G.

The stations (on Figure 3.1 and 3.2) are identified by the 7 digit Water Survey Number. The boxes on the left from the top refer to the L-moments 7 day flow (m^3/s) with a recurrence interval of 2, 5, 10 and 20 years, followed by the minimum average 7 day flow and the period of record for the station. The boxes on the right from the top refer to the conventional estimations of 7 day flow (m^3/s) with a recurrence interval of 2, 5, 10 and 20 years. Other remaining boxes identify Minimum day, period of record (years) regulation identification (R or N) and watershed area (km^2).

Station names are also listed along with the station numbers for identification purposes on Figure 3.1 and 3.2.

3.3.5 Winter/Summer/Annual Low Flow Population Analysis

From the literature review it is apparent that seasonal low flows may belong to distinct populations. Further investigations were undertaken to assess this possibility. For the purposes of this investigation summer is defined by the period of May to October, and Winter is defined by the period of November to April. The low flows for winter and summer were then extracted for each station. The analysis results are given in Appendix C.

To analyze the low flow populations in winter, summer, and annual, the mean values and the standard deviations, for each low flow series over the recorded period of each station, were computed and compared. Table C.1 presents the comparison of the means and standard deviation for each of the stations in Northern Ontario Regions. Table C.2 tabulates the Mann-Kendall trend testing results. From Table C.1, it is clear that significant differences can be found among the statistics of annual/winter/summer low flow records. As an example, station 05QE006's mean annual low flow is equal to 88.25 m^3/s with standard deviation 45.82 m^3/s. The mean value of low flows for winter and summer are 131.74 and 105.56 m^3/s with standard deviation 63.46 and 61.06 m^3/s, respectively. It is interesting to note that the flow time series for winter displayed significant upward trend, but the summer low flow sequence showed downward trend.

Generally, it was found that the summer low flows are higher than the low flows from winter at most of the stations. The mean summer low flow of the entire region is equal to 46.2 m^3/s, while the mean winter low flow is 32.9 m^3/s. However, with reference to the raw data records, it is known that some winter low flows were measured under ice conditions. Therefore, the accuracy of flow measurements may not be comparable for summer and winter conditions.

For the purposes of the regional analysis, the annual low flow series was used since more conservative results should be obtained. However, for cases where assessment of seasonal discharges is important, a low flow analysis on a seasonal basis should be considered.

3.3.6 Summary of Data Analysis and Low Flow Characteristics

Application of various non-parametric tests was undertaken for the available data base. The test results (Table 3.1) indicate that the available data base of extreme low flows may exhibit some trend and dependence with some possibility of non-random and non-homogeneous characteristics. Previous widespread application of the tests utilized have not been found in the literature describing low flow analyses.

The average length of record for the stations analysed in these regions is 26 years. It is possible that the available record lengths are too short to permit reasonable application and interpretation of these non-parametric test results. Another possibility, which should be investigated in more detail, is that the available low flow data sets do exhibit trend and non-random characteristics. The latter could possibly be attributed to slow cyclic changes in groundwater levels, seasonal effects, or climatic trends. This should be investigated in more detail since the underlying assumptions for application of the extreme value distribution and subsequent regression analyses are called into question.

A winter/summer/annual low flow population analysis was undertaken. The results indicated that the winter, summer, and annual low flows are from different populations for some of the stations. Generally speaking, the low flows from summer records are higher than the winter low flows at most of the stations. Therefore, where assessment of seasonal discharges is important, it may be more appropriate to undertake the analysis of low flow regionalization for different seasons. However, this would result in less conservative estimates of the annual average 7 day low flow and hence less conservative extreme low flows (re. $7Q_{20}$).

The Gumbel Extreme Value (Weibull) Distribution was generally found to adequately fit the available low flow series for various low flow durations.

Extreme value analyses were undertaken on an annual basis for 114 stations. A total of 93 stations were retained for analysis and 21 for additional testing of results.

The data analyses were undertaken for both regulated and unregulated data series. Therefore, care should be taken in comparison and interpretation of results, notably for data series which may include the effects of regulation.

Figure 3.1 and 3.2 summarized the low flow characteristics for the 7 day extreme values for the 2, 5, 10 and 20 year recurrence intervals.

Data analysis and management techniques are now available which would allow efficiently updating the present analyses on a frequent basis. In our opinion, the low flow analyses should be updated every five years in order to provide reasonably accurate information for investigations requiring low flow information.

3.4 Physiographic and Meteorologic Data

3.4.1 Criteria

The review of background information (see Section 2.0) identified several criteria for selection of appropriate physiographic and climatic parameters which might be suitable for use in regionalizing low flow characteristics. These are discussed as follows:

i) Statistical Significance

When undertaking a multivariate analysis, the variables chosen must make a contribution to explaining the variance of the low flows. The experience in undertaking similar investigations (discussed in Section 2.0) was used to identify parameters which have proven to be statistically significant in predicting low flows.

ii) Physical Characteristics

Wherever possible, variables should be selected based on hydrologic significance. That is, the parameters should have some physical meaning with regard to estimates of low flows.

iii) Reliability of Computation

It is preferable to select parameters which can easily be computed in a reliable manner by users who may not be familiar with regression procedures or the details of the statistical concepts. Therefore, from a practical point of view, it was desirable to make the parameter estimation procedure as uncomplicated as possible in order to minimize computation errors when applying the estimation technique.

3.4.2 Parameters

The parameters selected for use in this study are listed as follows:

Hydrometeorologic Data	Symbol
Index of mean annual precipitation at gauge location (mm) (Figure F.1)[1]	MAP
Index of mean annual snowfall at gauge location (cm) (Figure F.2)	MAS
Index of mean annual runoff at gauge location (mm) (Figure F.3)	MAR
Index of mean annual evaporation at gauge location (mm) (Figure F.4)	EVA

Physiographic Data	
Drainage area (km^2)	DA
Index of area controlled by lakes and swamps	ACLS
Length of main channel (km)	LNTH
Base Flow Index (dimensionless ratio)	BFI
Regulation Index (0 - natural, 1 - regulated)	RN

Definition of Parameters and a brief discussion of derivation is discussed in the following sections:

DA (km^2)

The watershed drainage area was obtained from records published by the Water Survey of Canada.

ACLS (%)

An index representing the percentage of the drainage area controlled by lakes and swamps (ACLS) was obtained from records available in the report Regional Flood Frequency Analysis (Moin and Shaw, 1986) published by Environment Canada.

---

[1] Note: Index maps used to derive hydrometeorologic data are given in Appendix F.

LNTH (km)

The length of the main channel was utilized from the Regional Flood Frequency Analysis (Moin and Shaw, 1986) and published by Environment Canada. The lengths for some stations were not previously calculated. For these stations the lengths were scaled from review of Water Survey of Canada watershed boundaries which delineated rivers on 1:50,000 and 1:250,000 scale NTS maps.

Base Flow Index (BFI) (Dimensionless Ratio)

This parameter is an indicator of the hydrogeological effects of the drainage basin soil and geology type and also the retention characteristics (primarily due to lakes and swamps) of the drainage basin. BFI is defined as:

$$\text{BFI} = \frac{\text{Total Volume of Base Flow}}{\text{Total Volume of Runoff}}$$

The median values calculated for all Ontario gauging stations having at least 2 years of continuous daily discharge data were plotted at the corresponding drainage basin centroid using 1:600,000 scale base maps for Southern Ontario and isolines drawn. The centroid were located by eye after delineating the drainage area. An isoline map was prepared to help provide estimates of BFI for ungauged basins when applying the regression equations (Regional Flood Frequency Analysis, Moin and Shaw, 1986). All estimates of BFI from the isoline maps must be made by first locating the basin centroid and then projecting this point to the closest point on the main channel. The BFI is then interpolated from the isolines at this location on the main channel. A better BFI estimate will be obtained for large basins and in areas where the isolines are very close together, if an average value of BFI, weighted by the area between isolines, is taken over the entire drainage basin.

RN

Regulation code (i.e. an indication of possible regulation):

0 - Natural, non-regulated	(N on Figure 3.1 and 3.2)
1 - Regulated	(R on Figures 3.1 and 3.2)

NOTE: Heavily regulated stations were not included in the analysis. A simple correlation analysis indicated insignificant levels of correlation with the observed low flows for the stations remaining.

MAP (mm)

An index of mean annual precipitation was developed with reference to available publications (MNR, 1984, Environment Canada, 1978 and Flood Frequency Analysis, Moin and Shaw, 1986). The index of mean annual precipitation is interpolated for each watershed used in the analysis at the gauge location.

MAS (mm)

An index of mean annual snowfall was obtained from available information published by the Ministry of Natural Resources (MNR, 1984) and Fisheries and Environment Canada , 1978. The index map was used to derive a snowfall index for each watershed. This index represents total annual snowfall for each watershed as determined at the gauge location.

MAR (mm)

The index of mean annual runoff is expressed as a depth of water averaged over the drainage basin area. The isolines of runoff were obtained from existing information published by Environment Canada and adopted by the Ministry of Natural Resources (Sangal and Kallio, 1977, MNR, 1984 and Flood Frequency Analysis, Moin and Shaw, 1988). The mean annual runoff index was derived for each hydrometric station at the gauge location.

EVA (mm)

An index for the mean annual evaporation was obtained from the publications by Fisheries and Environment Canada, 1978. The mean annual evaporation index was derived for each hydrometric station at the gauge location.

3.4.3 Summary of Physiographic and Meteorologic Data

Tables 3.8 (a) and 3.8 (b) summarize the parameters which were determined for each station remaining after screening for the Northwestern and Northeastern Regions, respectively. Tables 3.9 (a) to 3.9 (f) summarizes the mean, range and other simple statistics of the data base for various sub-regions in Northern Ontario (see Section 3.5)

TABLE 3.8(a)
DATA BASE, PARAMETERS USED IN REGRESSION
NORTHWESTERN REGION

Station Number	# of Years	Region Code	RN*	LAT (0)	LONG (0)	MAP mm	MAS mm	MAR mm	EVA mm	DA km^2	BFI	LNTH km	ACL (%)	7Q2 m^3/s	7Q20 m^3/s
02AA001	68	3	0	44.0544	83.3658	800	230	292	500	1550	0.68	110	35	2.07	0.62
02AB006	64	3	1	48.3158	89.3539	785	232	297	500	6480	0.76	184	74	24.6	12.48
02AB009	34	3	1	48.332	89.4055	785	230	285	500	2800	0.7	162	55	4.49	2.37
02AB010	68	3	1	48.2456	89.3751	785	235	250	500	6710	0.71	183	60	21.12	10.98
02AB014	19	3	0	48.3004	89.1047	780	240	355	500	111	0.38	32.5	29	0.08	0.004
02AB015	14	3	1	48.321	89.141	780	240	327	500	492	0.62	44.25	97	0.52	0.24
02AB016	14	3	1	48.2507	89.1555	780	230	307	500	145	0.36	39.5	8	0.06	0
02AC001	20	3	0	48.4919	88.3207	785	240	299	495	736	0.67	45	10	0.67	0.26
02AD010	20	3	0	49.361	87.57	788	250	334	490	650	0.58	20	100	0.88	0.51
02AE001	17	3	0	48.5534	87.4127	805	245	382	480	616	0.59	15	0	0.81	0.31
02BA002	21	3	0	49.464	86.5304	840	230	389	490	1190	0.84	107.5	98	2.54	1.71
02BB002	24	3	0	48.412	86.1245	875	240	449	500	1980	0.64	150	71	3.93	2.49
02BB003	21	3	0	48.4626	86.1749	860	240	367	500	4270	0.66	465	55	7.12	4.52
04CA002	14	1	0	53.2927	91.3055	590	195	255	380	36500	0.98	305	100	95.44	44.03
04CA003	24	1	0	52.392	92.3215	590	200	294	390	619	0.65	59.06	20	0.62	0.23
04CB001	24	1	0	53.2055	91.473	590	200	325	390	10800	0.98	294.0	60	42.93	27.2
04CC001	19	1	0	55.223	89.193	595	230	236	340	94300	0.89	400	0	165.2	104.9
04CD002	20	1	0	53.594	92.055	55	190	273	350	4270	0.98	161.9	100	12.6	10.15
04CE002	23	1	0	53.46	89.33	600	230	287	370	4350	0.98	98.43	100	23.62	16.65
04DA001	25	1	0	52.345	90.112	650	240	337	380	5960	0.85	203.2	40	8.98	5.64
04DC001	14	1	0	54.3107	87.14	590	220	299	340	50000	0.94	419.7	80	86.23	58.67
04DC002	24	1	0	54.17	85.39	500	210	289	340	4710	0.61	155.9	0	2.62	1.13
04FA001	25	1	1	51.492	89.36	700	260	341	400	9010	0.86	227.3	100	16.05	12.14
04FA002	24	1	1	51.384	89.533	700	260	354	400	1540	0.85	165	50	3	2.02
04FA003	25	1	0	52.185	88.4515	690	260	289	400	4900	0.77	273.1	30	6.38	3.54
04FC001	23	1	0	53.053	85.003	650	230	334	390	36000	0.88	317.5	95	55.27	43.77
04GA002	23	3	0	51.1	91.355	720	230	234	400	5390	0.99	163.8	100	13.51	1.05
04GB004	20	3	0	50.52	88.555	740	260	193	420	11200	0.86	187.3	100	42.84	35.44
04GC002	16	1	1	51.22	89.252	735	260	108	410	16300	0.96	197	60	17.56	7.21
04GD001	22	1	1	51.6417	86.3972	710	250	248	410	32400	0.96	228.2	100	56.57	30.23
04JA002	37	1	0	49.9439	84.0613	810	300	403	410	3780	0.86	187.9	74	10.37	6.71
04JC002	41	1	0	49.4644	84.3148	810	300	317	415	2410	0.81	105	50	4.41	2.15
04JF001	22	1	0	50.393	86.3157	770	300	308	410	5360	0.86	182.9	100	12.18	6.8
05PA012	64	2	1	48.0455	91.391	750	220	276	510	4510	0.87	128.2	100	10.15	3.77
05PB009	28	2	1	48.444	92.1705	790	220	242	505	5880	0.77	160	70	10.39	0.47
05PC018	11	2	1	48.3804	93.5447	750	228	228	515	50200	0.83	99	0	144	72.34
05PC019	30	2	1	44.365	93.24	755	220	226	515	38600	0.78	189	100	117.5	41.21
05PD026	22	2	1	49.263	93.59	740	220	154	500	744	0.79	27.5	100	0.4	0
05QA001	60	2	0	50.0415	91.564	790	220	273	500	13900	0.99	238.1	100	49.76	23.4
05QC001	29	2	1	50.522	93.29	720	220	406	490	4920	0.91	101.7	90	7.5	0.99
05QD003	27	2	0	49.472	93.114	775	225	195	510	2510	0.91	47	90	4.3	0.02
05QD006	28	2	1	49.572	93.235	770	220	225	510	6370	0.83	80.2	80	19.11	6.21
05QD016	21	2	1	49.4945	92.5215	775	230	169	510	2300	0.81	40.5	80	3.65	0.46
05QE006	49	2	1	50.38	93.123	700	200	253	490	26400	0.94	122.5	100	85.43	18.45
05QE007	35	2	1	50.3501	93.2715	695	200	295	490	37000	0.68	131.1	50	144.5	31.68
05QE008	21	2	0	50.303	93.153	750	190	195	490	1690	0.97	87.6	100	3.71	1.9
05QE009	31	2	0	50.212	94.273	760	190	223	490	1530	0.9	92.71	50	2.71	0.97

* 1 – Regulated
0 – Natural

TABLE 3.8(b)
DATA BASE, PARAMETERS USED IN REGRESSION
NORTHEASTERN REGION

Station Number	# of Years	Region Code	RN*	LAT (0)	LONG (0)	MAP mm	MAS mm	MAR mm	EVA mm	DA km^2	BFI	LNTH km	ACL (%)	7Q2 m^3/s	7Q20 m^3/s
02BF001	24	3	0	46.59	84.313	1000	300	598	520	1190	0.53	103	58	303	1.64
02BF002	24	3	0	46.51	83.581	895	300	516	520	1160	0.57	84.5	83	2.45	0.91
02BF004	12	3	0	46.31	84.275	900	300	486	520	51.5	0.34	27.6	100	0.04	0.02
02BF006	12	3	0	47.03	84.244	895	300	799	520	8.64	0.55	11.7	50	0.01	0
02CA002	20	3	0	46.33	84.165	930	300	563	525	108	0.35	17.5	24	0.07	0.01
02CC007	41	3	1	46.26	83.230	890	290	377	510	6840	0.56	77.6	100	18.48	1.63
02CC008	40	3	1	46.12	83.013	885	270	423	510	9300	0.64	88.9	100	38.88	17.23
02CC009	31	3	1	46.18	83.172	885	280	390	510	9010	0.57	86	100	31.43	7.32
02CC010	11	3	1	46.34	82.575	890	285	416	510	1190	0.58	47	50	4.09	2025
02CD001	25	3	0	46.12	82.303	900	255	508	500	1350	0.81	56	100	2.6	0.6
02CD002	14	3	1	46.29	82.383	900	250	502	500	109	0.53	7.6	70	0.06	0
02CD004	22	3	1	46.22	82.261	900	250	544	500	567	0.84	35	50	1.59	0.26
02CD006	23	3	0	46.31	82.37	900	255	575	500	157	0.7	4.5	100	0.61	0.26
02CE001	44	3	1	46.16	81.462	890	250	366	490	11400	0.71	147	30	43.56	22.6
02CE002	76	3	1	46.12	82.041	880	250	430	490	1350	0.77	128	72	3.99	2.6
02CF007	31	3	0	46.34	81.115	795	250	356	490	243	0.55	24.5	19	0.51	0.31
02CF010	15	3	1	46.36	81.225	800	250	242	490	1570	0.63	88	50	1.71	0.8
02CF012	14	3	0	46.25	81.055	800	260	497	490	207	0.57	31	20	0.79	0.39
02DB007	11	3	0	46.28	80.491	805	260	679	490	59	0.38	35	0	0.14	0.01
02DC003	70	3	1	46.27	79.514	830	270	413	480	6660	0.78	170	70	29.49	11.97
02DC008	52	3	1	46.40	79.594	825	265	422	480	2360	0.71	145	100	0.51	0.003
02DD005	47	3	1	46.05	79.284	830	270	471	500	787	0.58	41	100	2.15	0.75
02DD009	35	3	1	45.50	79.224	890	270	634	500	316	0.67	30	10	1.54	0.54
02DD010	30	3	1	46.03	80.342	850	270	414	500	13900	0.93	120.	50	42.89	25.36
02DD013	17	3	0	46.15	79.234	860	270	443	500	70.4	0.36	3	100	0.06	0.01
02EA005	76	3	0	45.46	79.224	930	290	576	510	321	0.66	43.6	91	0.69	0.31
02EA006	76	3	1	45.37	79.231	930	290	523	510	650	0.76	63	90	1.89	0.5
02EA010	23	3	0	45.12	79.183	920	280	626	510	149	0.5	36	28	0.36	0.19
02EA011	18	3	1	45.46	80.284	935	280	522	510	2850	0.66	97	80	5.13	1.58
02EA013	11	3	0	45.11	80.262	940	280	530	510	35.5	0.66	4.5	80	0.01	0
02JC008	23	3	0	47.53	79.524	790	280	390	470	1780	0.64	95.3	80	3.82	2.38
02JD010	19	3	1	47.08	79.271	830	280	368	470	6600	0.23	132	100	14.63	1.98
02JE012	39	3	1	46.22	78.432	850	260	454	470	47900	0.71	105	90	365.5	225.1
02JE018	12	3	0	47.25	79.315	850	260	336	470	62.9	0.63	15.5	94	0.04	0
02JE019	19	3	1	46.18	78.524	850	260	470	470	1130	0.79	77.5	100	3.64	1.82
02JE020	20	3	1	46.17	78.542	850	260	537	470	909	0.59	39.1	100	1.49	0.88
04KA001	21	1	0	51.09	80.52	720	220	277	370	4250	0.56	229.	0	1.09	0.41
04LA001	22	1	1	48.23	81.265	830	220	372	450	5540	0.79	150.	50	25.91	17.73
04LF001	73	1	1	49.25	82.261	820	300	363	440	6760	0.68	236.	0	12.15	4.85
04LG002	24	1	1	50.48	81.174	760	220	410	370	60100	0.69	476.	0	166.1	95.99
04LJ001	71	1	0	49.37	83.151	820	300	370	420	8940	0.67	335.	18	11.15	4.86
04LM001	19	1	0	50.35	82.07	780	250	339	390	22900	0.53	396.	7	22.45	13.45
04MD004	14	1	0	48.33	81.052	815	300	456	410	401	0.49	25	90	0.58	0.29
04ME002	59	1	1	49.52	81.34	760	305	418	400	22900	0.64	167	0	144.3	98.1
04ME003	32	1	1	50.36	81.25	750	305	449	400	27500	0.66	259	19.5	172	130.1
04MF001	25	1	0	51.05	80.46	720	220	430	390	6680	0.65	123.	0	6.03	2.8

* 1 – Regulated
0 – Natural

TABLE 3.9(a)
SUMMARY OF SIMPLE STATISTICS OF THE
METEOROLOGICAL AND PHYSIOGRAPHIC DATA
NORTHERN ONTARIO

Variable	Mean	S. Dev.	Skewness	Minimum	Maximum	# of Stations	Lable
Years	29.5	17.7	1.39	11	76	93	Years of Record
RN	0.5	0.5	0.02	0	1	93	Reg. Code O−N, 1−R
MAP	788.1	97	−0.63	500	999	93	Mean Annual Precipitation (mm)
MAS	249.3	32.2	0.01	190	305	93	Mean Annual Snowfall (mm)
MAR	368.7	125.5	0.62	108	799	93	Mean Annual Runoff (mm)
EVA	465.3	52.7	−0.95	340	525	93	Mean Annual Evaporation (mm)
DA	8422.3	15057.5	3.12	8.6	94300	93	Drainage Area (km^2)
BFI	0.72	0.18	−0.46	0.23	0.99	93	Base Flow Index
LNTH	122.8	109.4	130	3	476.3	93	Stream Length (km)
ACLS	65	36.1	−0.61	0	100	93	Area Controled By Lake and Swamps (%)
Q2	24.22	41.71	2.33	0.01	172	93	$7Q_2$ (m^3/s)
Q20	12.75	24.96	3.09	0	130.1	93	$7Q_{20}$ (m^3/s)

TABLE 3.9(b)
SUMMARY OF SIMPLE STATISTICS OF THE
METEOROLOGICAL AND PHYSIOGRAPHIC DATA
NORTHWESTERN REGION

Variable	Mean	S. Dev.	Skewness	Minimum	Maximum	# of Stations	Lable
Years	28.9	15.4	1.51	11	68	47	Years of Record
RN	0.44	0.5	0.24	0	1	47	Reg. Code O–N, 1–R
MAP	728	83.5	−0.87	500	875	47	Mean Annual Precipitation (mm)
MAS	230.2	26.6	0.72	190	300	47	Mean Annual Snowfall (mm)
MAR	282.9	68.8	−0.004	108	449	47	Mean Annual Runoff (mm)
EVA	453.4	57.9	−0.62	340	515	47	Mean Annual Evaporation (mm)
DA	11218.9	17934.7	2.64	111	94300	47	Drainage Area (km^2)
BFI	0.81	0.16	−1.2	0.36	0.99	47	Base Flow Index
LNTH	144.88	110.29	0.98	4	465	47	Stream Length (km)
ACLS	69.3	34.2	−0.83	0	100	47	Area Controled By Lake and Swamps (%)
Q2	29.9	42.4	1.82	0.06	165.2	47	$7Q_2$ (m^3/s)
Q20	14.5	21.9	2.42	0	104.9	47	$7Q_{20}$ (m^3/s)

TABLE 3.9(c)
SUMMARY OF SIMPLE STATISTICS OF THE
METEOROLOGICAL AND PHYSIOGRAPHIC DATA
NORTHEASTERN REGION

Variable	Mean	S. Dev.	Skewness	Minimum	Maximum	# of Stations	Lable
Years	30.23	20.19	1.26	11	76	46	Years of Record
RN	0.55	0.5	−0.22	0	1	46	Reg. Code O−N, 1−R
MAP	854.55	61.09	−0.27	720	999	46	Mean Annual Precipitation (mm)
MAS	270.4	23.6	−0.46	220	305	46	Mean Annual Snowfall (mm)
MAR	463.6	103.6	0.65	242	799	46	Mean Annual Runoff (mm)
EVA	478.4	4316	−1.33	370	525	46	Mean Annual Evaporation (mm)
DA	5328.1	103824	3.73	8.64	60100	46	Drainage Area (km^2)
BFI	0.63	0.15	−0.36	0.23	0.93	46	Base Flow Index
LNTH	98.29	104.11	1.9	3	476.3	46	Stream Length (km)
ACLS	60.3	37.8	−0.4	0	100	46	Area Controled By Lake and Swamps (%)
Q2	18.34	40.12	3.22	0.01	172	46	$7Q_2$ (m^3/s)
Q20	10.8	27.6	3.54	0	130.1	46	$7Q_{20}$ (m^3/s)

TABLE 3.9(d)
SUMMARY OF SIMPLE STATISTICS OF THE
METEOROLOGICAL AND PHYSIOGRAPHIC DATA
REGION ONE

Variable	Mean	S. Dev.	Skewness	Minimum	Maximum	# of Stations	Lable
Years	27.9	15.4	2.1	14	73	28	Years of Record
RN	0.32	0.48	0.81	0	1	28	Reg. Code O−N, 1−R
MAP	700.5	94.9	−0.4	500	830	28	Mean Annual Precipitation (mm)
MAS	249.1	38.7	0.23	190	305	28	Mean Annual Snowfall (mm)
MAR	330.1	74.3	−0.7	108	456	28	Mean Annual Runoff (mm)
EVA	391.3	27.5	−0.22	340	450	28	Mean Annual Evaporation (mm)
DA	18160	21661	2	401	94300	28	Drainage Area (km^2)
BFI	0.79	0.15	−0.38	0	1	28	Base Flow Index
LNTH	229	111.6	−0.4	25	476.3	28	Stream Length (km)
ACLS	50.5	40.9	−0.02	0	100	28	Area Controled By Lake and Swamps (%)
Q2	43.7	55.1	1.48	0.58	172	28	$7Q_2$ (m^3/s)
Q20	27.7	36.64	1.65	0.23	130.1	28	$7Q_{20}$ (m^3/s)

TABLE 3.9(e)
SUMMARY OF SIMPLE STATISTICS OF THE
METEOROLOGICAL AND PHYSIOGRAPHIC DATA
REGION TWO

Variable	Mean	S. Dev.	Skewness	Minimum	Maximum	# of Stations	Lable
Years	31.4	14.9	1.03	11	64	14	Years of Record
RN	0.75	0.45	−1.28	0	1	14	Reg. Code O−N, 1−R
MAP	747.5	29.7	−0.31	695	790	14	Mean Annual Precipitation (mm)
MAS	211.75	14.66	−0.54	190	230	14	Mean Annual Snowfall (mm)
MAR	238.3	58.2	1.51	154	406	14	Mean Annual Runoff (mm)
EVA	500.3	10.2	0.17	490	515	14	Mean Annual Evaporation (mm)
DA	12284.6	16312.8	1.4	744	50200	14	Drainage Area (km^2)
BFI	0.86	0.09	−0.18	0.68	0.99	14	Base Flow Index
LNTH	97.14	64.9	0.47	4	238.1	14	Stream Length (km)
ACLS	81.9	27.9	−1.99	0	100	14	Area Controled By Lake and Swamps (%)
Q2	43.2	53.3	0.94	0.4	144.5	14	$7Q_2$ (m^3/s)
Q20	14.5	20.6	1.94	0	72.3	14	$7Q_{20}$ (m^3/s)

TABLE 3.9(f)
SUMMARY OF SIMPLE STATISTICS OF THE
METEOROLOGICAL AND PHYSIOGRAPHIC DATA
REGION THREE

Variable	Mean	S. Dev.	Skewness	Minimum	Maximum	# of Stations	Lable
Years	30.2	19.7	1.21	11	76	51	Years of Record
RN	0.53	0.5	−0.11	0	1	51	Reg. Code O−N, 1−R
MAP	849.2	58.4	0.06	720	999	51	Mean Annual Precipitation (mm)
MAS	261.5	21.2	0.23	230	300	51	Mean Annual Snowfall (mm)
MAR	430.7	121.5	0.42	193	799	51	Mean Annual Runoff (mm)
EVA	494.2	21.6	−2.29	400	525	51	Mean Annual Evaporation (mm)
DA	3212.2	7019	5.08	8.64	47900	51	Drainage Area (km^2)
BFI	0.64	0.17	−0.28	0.23	0.99	51	Base Flow Index
LNTH	77.42	76.99	2.54	3	465	51	Stream Length (km)
ACLS	68.02	33.45	−0.67	0	100	51	Area Controled By Lake and Swamps (%)
Q2	14.37	49.81	6.73	0.01	365.5	51	$7Q_2$ (m^3/s)
Q20	7.46	30.69	6.86	0	225.1	51	$7Q_{20}$ (m^3/s)

Other general physiographic information was referred to during the identification of sub-regions for Northern Ontario. With reference to Appendix F Figure F.8 illustrates general variations in surficial geology; Figure F.5 summarizes overall variations in annual groundwater contribution to local streamflow; and Figure F.6 summarizes, in a general way, the variations in groundwater yield from bedrock.

3.5 Sub-Regions

3.5.1 General

Previous investigations have indicated that the accuracy of prediction of low flows for ungauged watersheds can be increased somewhat by definition of statistically or physically homogeneous sub-regions. For the purpose of this investigations, three sub-regions were identified based on preliminary development of prediction methods (see Figure 3.4). The hydrologic characteristics of the sub-regions are summarized in Table 3.10, from which it is evident that there appears to be broad differences in meteorologic, physiographic and low flow characteristics supporting the use of a sub-regional analysis. The development and testing of low flow prediction techniques was undertaken for each of the sub-regions in an effort to evaluate the possibility of improving low flow estimates.

Three statistical tests were also applied in an effort to confirm the identification of subregions (see Section 3.5.2, 3.5.3, and 3.5.4).

3.5.2 Statistical Homogeneity Test

A test for statistical homogeneity for each of the sub-regions was developed and applied in an effort to confirm regional homogeneity on a statistical basis. P.J. Pilon (1990) applied a homogeneity test, developed by T. Dalrymple (1960) for flood frequency analysis, for the three-parameter Weibull distribution. This technique was modified for application in the present low flow regionalization study. The statistical aspects of the test are described in Appendix D.1.

3.5.3 Heterogeneity Measure

A heterogeneity measure technique, developed by J.R.M. Hosking and J.R. Wallis (1993) for regional flood frequency analysis, was also applied to test the homogeneity of the sub-regions.

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	SUB REGIONS FIGURE 3.4

TABLE 3.10

COMPARISON OF SUB-REGIONS

Parameter	Region One	Region Two	Region Three
$7Q_{20}$ ($l/s/km^2$)	1.87 (23 stations)	0.74 (14 stations)	.99 (51 stations)
MAP (mm)	650 (500 - 800)	700 (600 - 800)	900 (800 - 900)
EVA (mm)	400 (300 - 500)	400 (300 - 500)	450 (400 - 500)
MAR (mm)	300 (200 - 400)	200 (150 - 250)	400 (300 - 500)
General Climate	sub-arctic boreal sub-humid to boreal moist	boreal sub-humid	cool temperature to boreal humid/moist
Surficial Soils	Surface ± 50% bedrock; limestone and dolomite towards Hudsons Bay	thin cover; some sands plus silt and clay	thin cover, some sands; gravels and igneous bedrock
General	Hudsons Bay, Lowland, James Bay	Lac Seul, Lake of Woods, Rainy Lake	numerous shoreline watersheds to Lake Superior/Lake Huron
Sub-surface Yield	Bedrock well yield 50% < 1 l/s 50% ≥ 1 l/s	Bedrock well yield < 1 l/s	Bedrock well yield < 1 l/s

The purpose of this measure is to estimate the degree of heterogeneity in a group of sites and to assess whether they might reasonably be treated as a homogeneous region. Specifically, the heterogeneity measure compares the between-site variations in sample L-moments for the group of sites with what would be expected for a homogeneous region. The procedures for application of the heterogeneity measure are described in Appendix D.2.

3.5.4 Cluster Analysis

The possibility to delimitate homogeneous regions, based on the statistical characteristics of the selected characteristics of hydrometric stations, was also undertaken using a cluster analysis.

In cluster analysis, group membership for all cases is unknown. In fact, even the number of groups is often unknown. The goal of the analysis is to identify homogeneous groups or clusters. A commonly used method for forming clusters is the hierarchical cluster analysis (which is available in the SPSS package).

There are many criteria for deciding which cases or clusters should be combined at each step of the analysis. All of these criteria are based on a matrix of either distances or similarities between pairs of cases. The two cases combined are those that have the smallest distance (or largest similarity). Clusters are formed by grouping cases into bigger and bigger clusters until all cases are members of a single cluster. A brief description of the cluster analysis and results given in Appendix D.3.

3.5.5 Results and Conclusions

A broad comparison of meteorological, physical and low flow characteristics (see Table 3.10) has indicated that it might be possible to consider low flow prediction methods based on three sub-regions in Northern Ontario.

However, the statistical homogeneity testing (see Appendix D.1) failed to confirm the statistical homogeneity of low flows for each of the selected sub-regions. Our preliminary assessment of this homogeneity test, as applied to low flows, indicates that the test may be too rigorous to apply to the available data base due to the short record length of available data and the statistical characteristics. (i.e. the test is apparently less accurate for low flows than for flood flows due to the shape of the probability density function).

The results of the cluster analysis indicated that the stations in Northern Ontario could be divided into two groups, which are, a Large Drainage Area Group and a Small Drainage Area Group. The cutoff point is about 17,000 km^2. Among the 93 stations, 78 could be classified into the second group, while 15 stations are found in the first group.

The heterogeneity measure technique was found to confirm the homogeneity of the selected sub-regions in the sense of frequency distribution characteristics. Table 3.11 presents the results of this measure. The weighted standard deviation of the at-site sample L-CVs (represented by V in Table 3.11) present the variations of the L-CV of the regions. The expected V and its standard deviation from the simulation give the range of variation of the V statistics. The heterogeneity measure, which is the H value in Table 3.11, declares the region to be heterogeneous if H is sufficiently larger. The region would be regarded as "acceptable homogeneous" if $H < 1$, "possibly heterogeneous" if $1 \leq H < 2$, and "definitely heterogeneous" if $H \geq 2$. From Table 3.11, it is evident that the data base available for Northern Ontario is heterogeneous (because $H = 2.48$ and is larger than 2). The Northwestern and Northeastern regions could be defined as possibly the heterogeneous regions and the sub-regions could be viewed as homogeneous. Therefore it is concluded that, the regionalization techniques could be applied to the sub-regions with some confidence.

Additional analysis using L-moments statistics (see plots of L-CV vrs. L-CS and L-CV vrs. L-CK in Appendix B) also confirmed regional homogeneity in regard to application of the frequency distribution.

It is also recognized that the available data base for region two (14 stations) may be insufficient to develop regionalization techniques. It could be postulated that the stations, in this region, may belong to a larger homogeneous area located between Ontario and Manitoba, although this requires further consideration in future investigations.

The ultimate objective of the sub-region analysis is to determine whether or not there would be an improvement in the regionalization of the low flow characteristics. The accuracy of predictions, by forming statistical based homogeneous regions (groups), will be discussed in Section 4.0.

3.6 Summary of Data Base

This section summarizes the main findings from the data base analysis for Northern Ontario, Northwestern and Northeastern and the three sub-regions.

TABLE 3.11

RESULTS OF HETEROGENEITY MEASURE (L-CV)

Region	V (recorded)	V^e (simulated)	Std. Dev. of V (simulated)	H
Northern Ontario	0.016	0.013	0.0014	2.48
Northwestern Ontario	0.024	0.019	0.0034	1.56
Northeastern Ontario	0.008	0.0065	0.0011	1.29
Sub-Region 1	0.0037	0.0031	0.00061	0.97
Sub-Region 2	0.0095	0.0083	0.0029	0.41
Sub-Region 3	0.022	0.020	0.0033	0.60

Note: $H < 1$ Homogeneous

$1 < H < 2$ Possibly Heterogeneous

$H > 2$ Heterogeneous

(500 simulations)

V weighted standard deviation of the at site L-CV's

V^e Simulated standard deviation of of L-CV

H Heterogeneity measure

Selected low flow characteristics were determined and are summarized on Figures 3.1 and 3.2 (with additional data in Appendix B).

Table 3.4 summarizes selected 7 day low flow statistics. It is apparent, from Table 3.4, that the mean values of low flows in Northern Ontario are above the average for the rest of Ontario. The mean low flow for the Northwestern Region is higher than that of Northeastern Region. The mean low flow for each of the three sub-regions are also distinguished from each other as shown in Table 3.4.

Table 3.5 summarizes the statistical characteristics for $7Q_2$, $7Q_5$, $7Q_{10}$, and $7Q_{20}$. It was confirmed that the three sub-regions identified do possess statistically different low flow characteristics. Table 3.6 tabulates the unit area 7-day low flows and unit area values also appear to be significantly different for Regions 1, 2, and 3.

Table 3.9 (a) through (f) summarizes ranges, means, and other statistics for the meteorological and physiographic data for the different regions. It also appears evident from Table 3.9 that it is appropriate to divide Northern Ontario into three sub-regions. Not only are the mean drainage area size for Region One and Two are much larger than the mean drainage area of Region Three, but the basic meteorological characteristics between Region One and Region Two are also quite different as is evident in Tables 3.9 (d), (e), and (f).

Table 3.8 (a) and 3.8 (b) summarize the data base used in low flow regionalization for Northern Ontario. Table 3.8 (a) is for the Northwestern Region, while Table 3.8 (b) is for the Northeastern Region. The three statistically based sub-regions shown on Figure 3.4 are represented by the appropriate code (1, 2, or 3) in Table 8. The regionalization then proceeded using the data in Table 8 and various data base analysis and graphical techniques (see Section 4.0).

4.0 REGIONALIZATION OF LOW FLOW CHARACTERISTICS

4.1 General

Four alternative methods for providing estimates of low flow characteristics for ungaged watershed were considered. They are; Multiple Linear Regression (Section 4.4), Mapped Isolines of unit low flows (Section 4.2), two types of Index Method (Section 4.3), and proration from nearby gauges (unit area technique) (Section 4.5). Emphasis was placed on determining $7Q_{20}$ and $7Q_2$ as these flows were identified to be the key low flow statistics required by the Ministry of the Environment and Energy. In addition to Northeastern and Northwestern Ontario, alternate prediction techniques were developed for the three sub-regions and the change in prediction accuracy was evaluated. Two statistically based homogeneous groups were also identified by means of cluster analysis and the relative prediction accuracy, based on the regression analysis, was evaluated.

4.2 Mapped Isoline Method

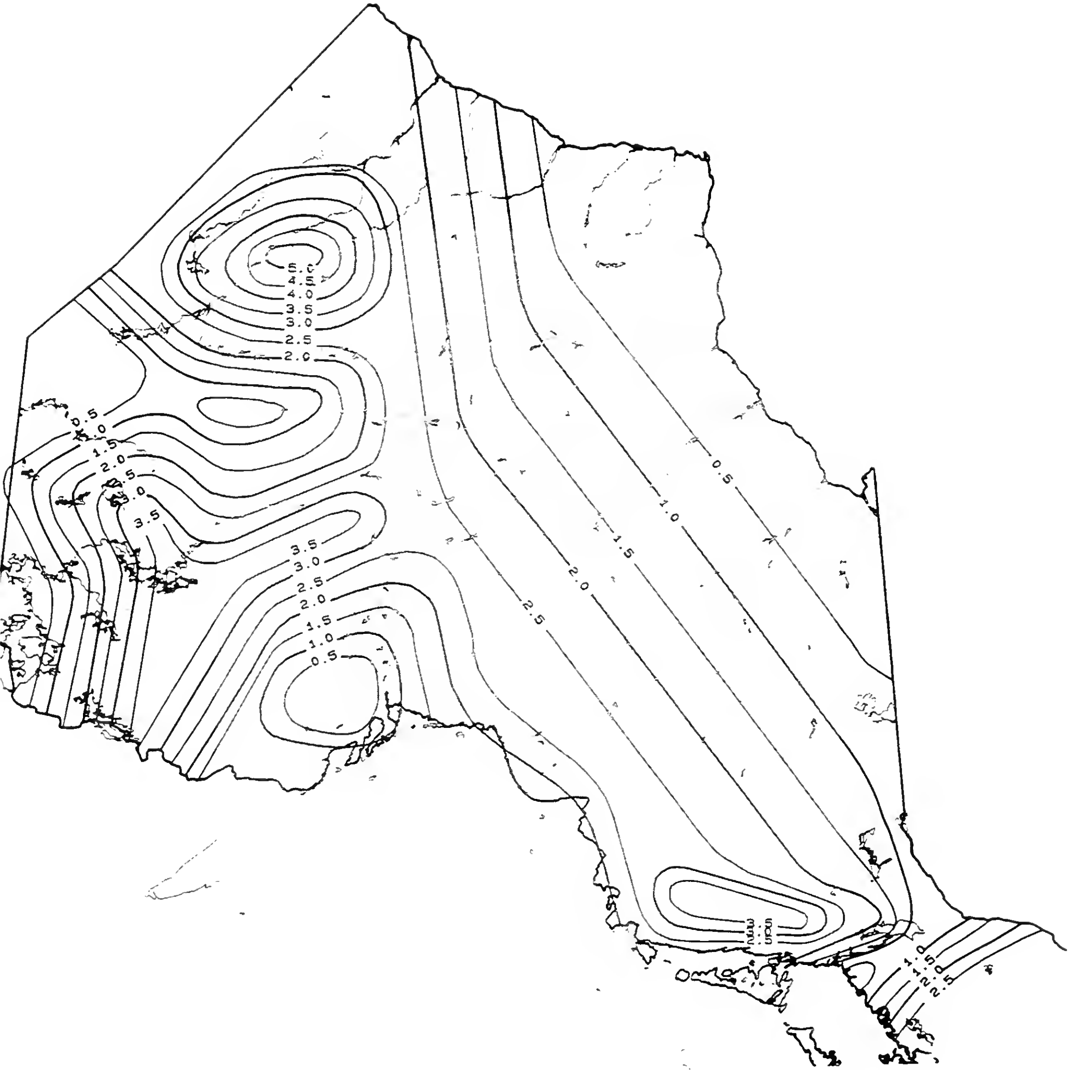
Isolines of unit area $7Q_2$ and $7Q_{20}$ low flows were drawn for the combined Northwestern and Northeastern regions (see Figures 4.1 and 4.2) using digital terrain modelling procedures and hand-drawn interpretations and modifications.

First, a digital terrain modelling package was used to create a triangulation matrix over the region to interpolate the location of "even values" isoline intersection points. The isolines were then created based on this interpolation (see Appendix G). The density of isolines is a reflection of station density. The higher density in the Northwestern region results in more closely packed isolines while the Northeastern region isolines are more spread out due to lower station density. Several patterns seem to become evident using this procedure. For example, there appears to be some kind of lake effect which influences isolines near Lake Superior and north of Lake Huron.

However, preliminary testing of low flow predictions found that the digital terrain modelling procedure was less accurate for low flow prediction than those from hand drawn interpretations using experience and judgement. This is attributed to the fact that the computer drawn isolines gave equal weight to all station values, independent of the station record and the quality of data. The computer drawn isolines (Appendix G) were then used as the overall basis for producing the final manually drawn isoline maps shown on Figures 4.1 and 4.2 for $7Q_2$ and $7Q_{20}$ respectively.

7Q2 ISOLINES
(MANUALLY)

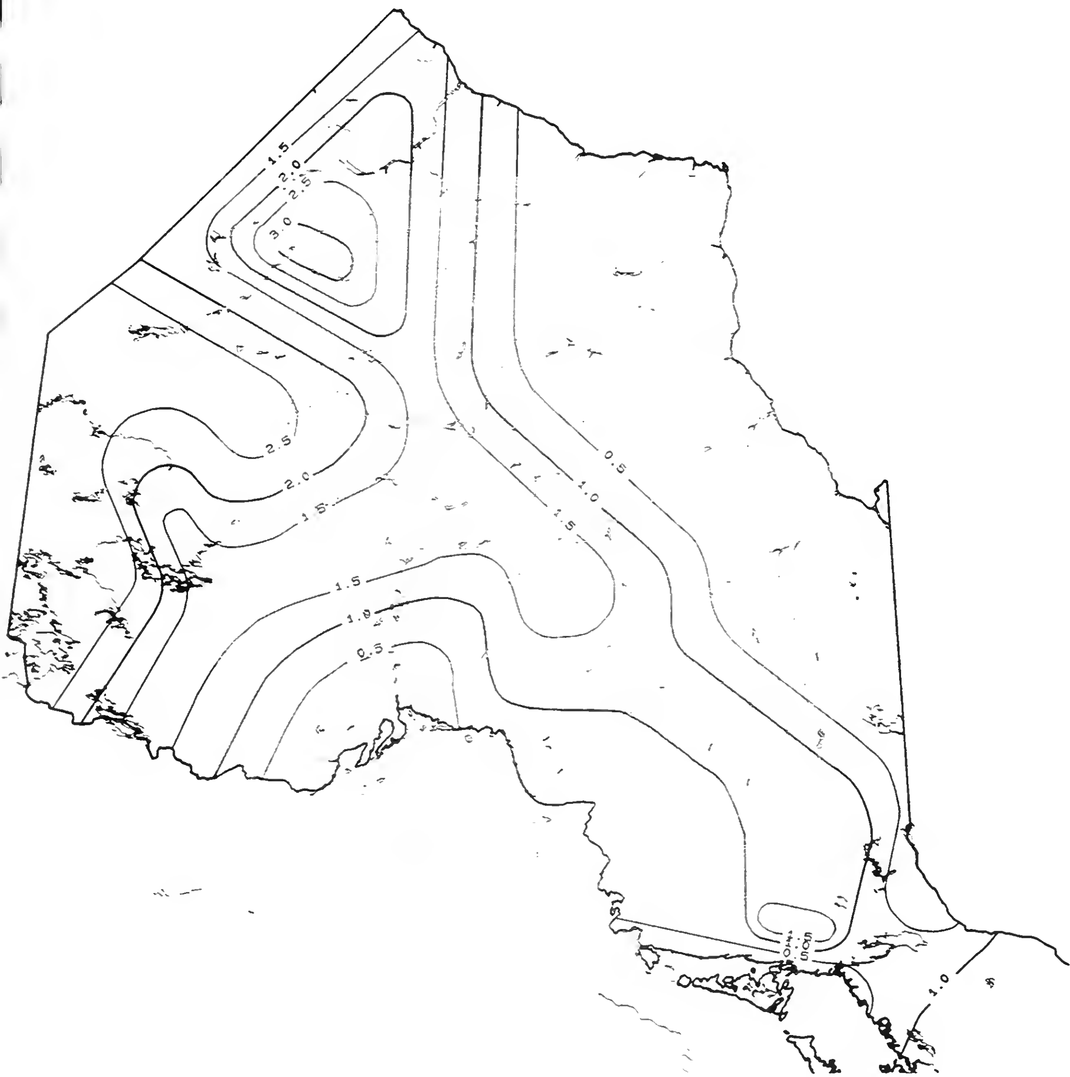
(l/s/km^2)



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	$7Q_2$ ISOLINES FIGURE 4.1

7Q20 ISOLINES
(MANUALLY)

(l/s/km²)



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	$7Q_{20}$ ISOLINES FIGURE 4.2

It should also be noted that consideration was also given to utilizing a non-linear data transform prior to isoline mapping. From the correlation analysis of $7Q_2$ with transformed parameters (see Table 4.2), it was found that no significant improvements could be expected by using a non-linear drainage area transform to predict $7Q_2$ for Region One and Two. However, a marginal improvement could be achieved by using DA^2 to estimate $7Q_2$ for Region Three. Other mapping transforms were also attempted, with no overall success in improvement of prediction accuracy. It was concluded that basing the overall isoline maps on the reciprocal of drainage area provided a consistent technique across the study area which maximized the use of the existing data base.

4.3 Index Methods

Index methods rely on determination of a selected low flow characteristic or index value from which a relationship to other low flow statistics can be derived or empirically determined. Two distinct index methods were considered and evaluated, namely:

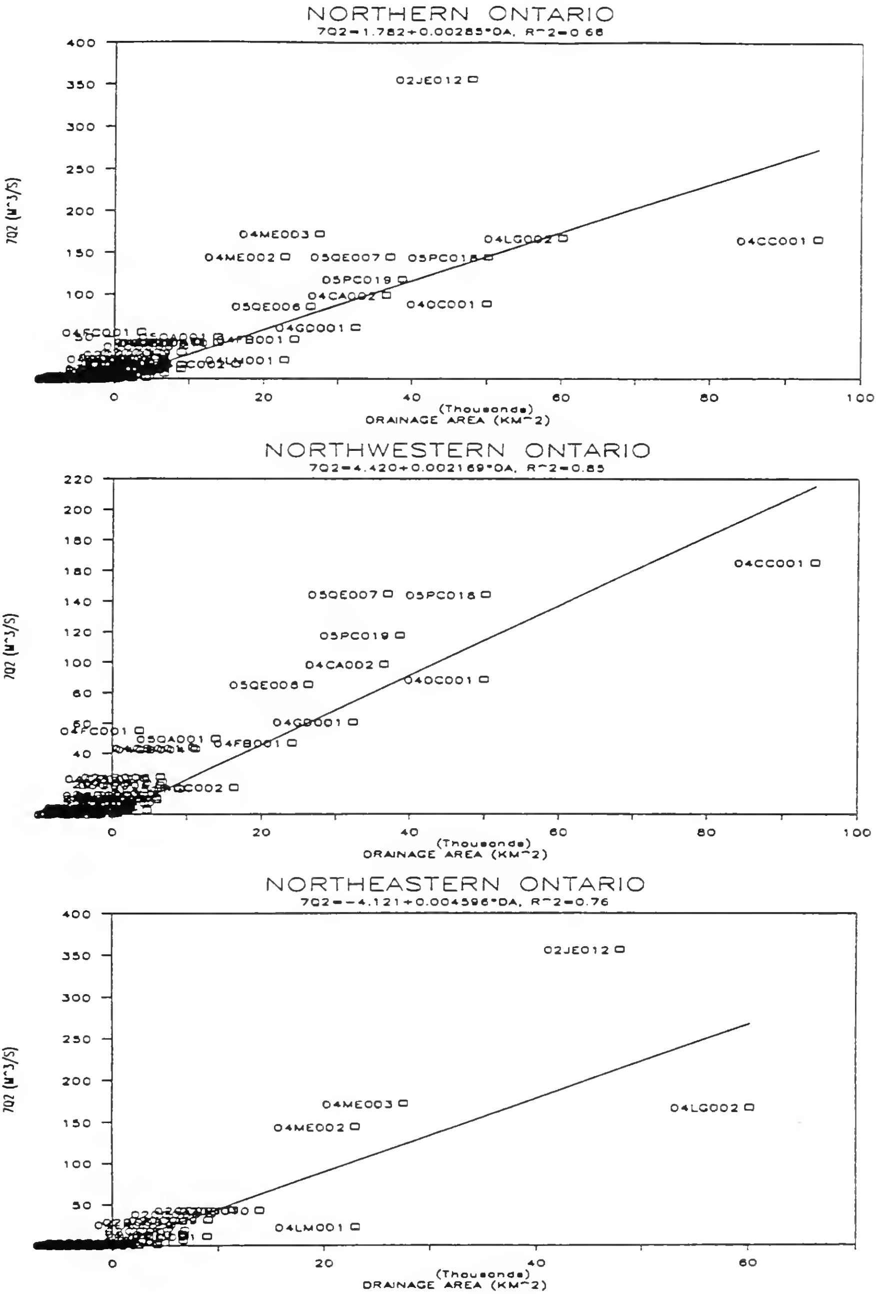
1) Graphical Index Method (Section 4.3.1)
2) Regional Index/Frequency Distribution Method (Section 4.3.2)

4.3.1 Graphical Index Method

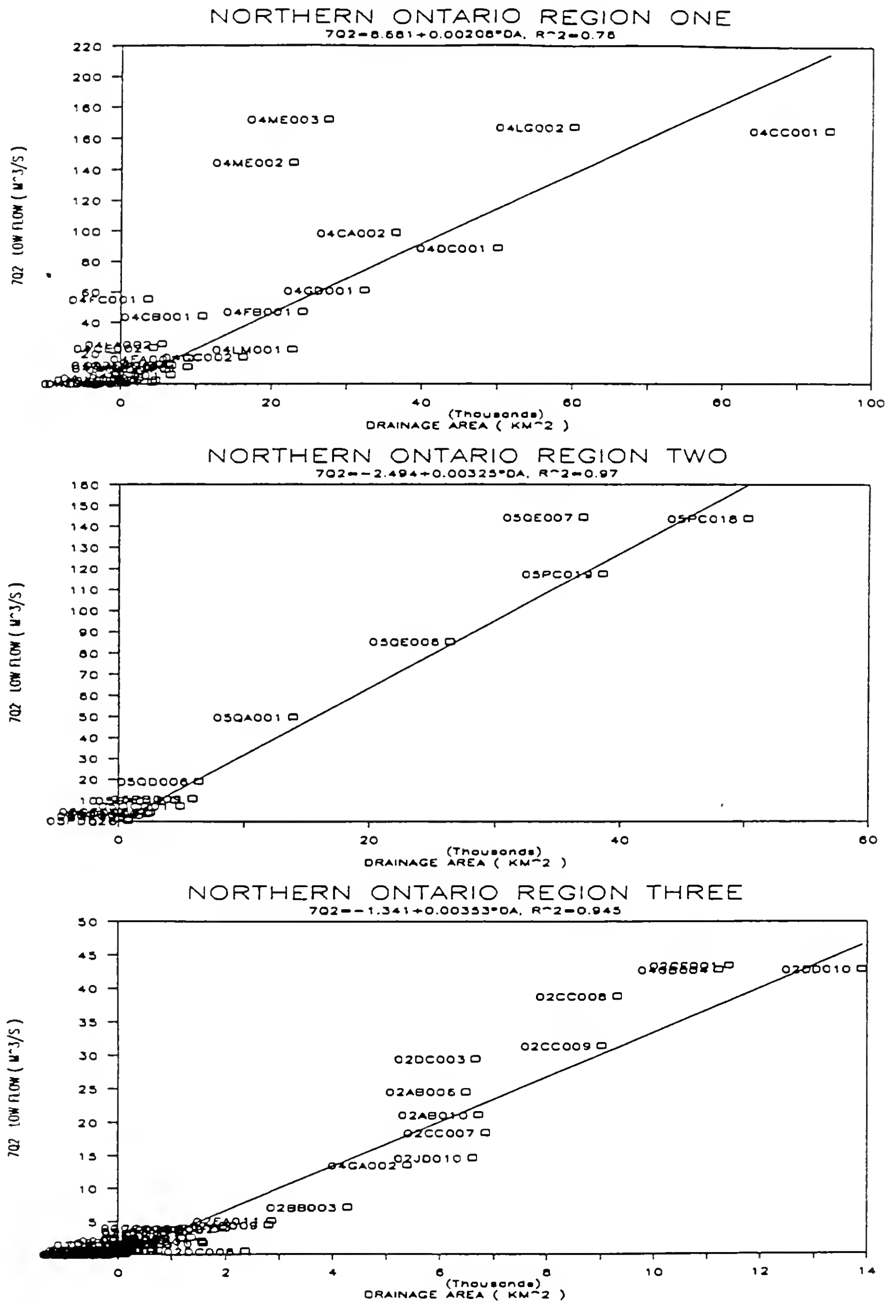
The regression analysis (see Section 4.4) confirmed the conclusions drawn from the literature survey that a predictor based on drainage area (DA) can provide good estimates of low flows. Therefore, a simple method, using DA alone to estimate low flows was investigated. First, graphs of $7Q_2$ as a function of DA were plotted as given on Figure 4.3, 4.4, and 4.5 for the total area, the Northwestern, Northeastern regions, sub-regions 1, 2, and 3 and the drainage area sizes. Figures 4.3, 4.4, and 4.5 also summarize the simple correlation of $7Q_y$ versus the drainage area and indicates that the drainage area is well correlated with $7Q_y$.

Previous studies have developed some interrelationships between n-day and 10-day average low flows (Cumming Cockburn Limited, 1990). Further to this, the ratio of $7Q_y$ to various n-day flows with Y year recurrence and the ratio of $7Q_y/7Q_2$ for all these regions was calculated and are given in Figure 4.6.

To use this method, knowing the drainage area, the $7Q_2$ index low flow could be estimated from Figure 4.3 or 4.4 depending upon the region in which the watershed of interest is located. When another $7Q_y$ is needed, one can find the ratio of $7Q_y/7Q_2$ from Figure 4.6 and then calculate the value of $7Q_y$. If another nQ_y flow is required, it can be estimated by using Figure 4.7 depending upon the region and the low flow to be estimated, by determining the appropriate



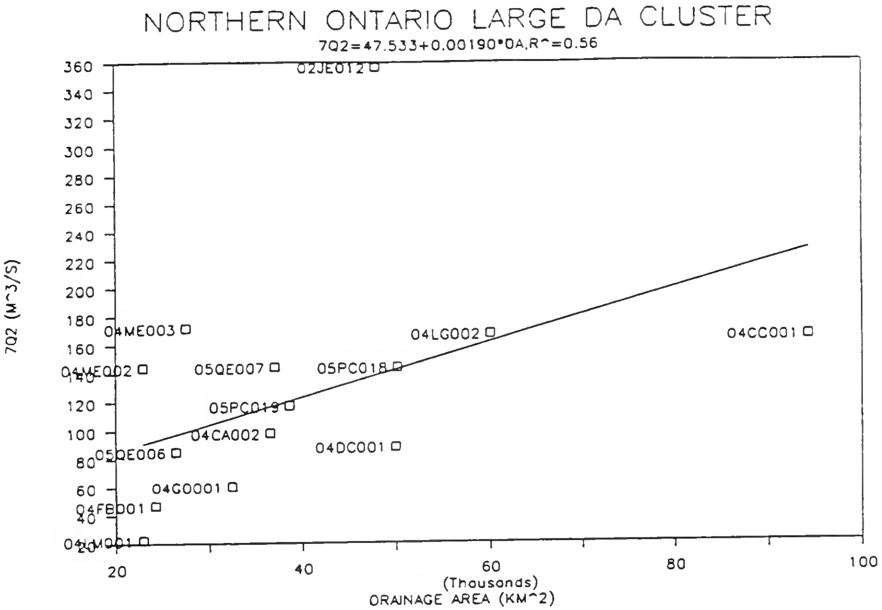
REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	INDEX METHOD NORTHERN ONTARIO, NW, NE, ($7Q_2$)
	FIGURE 4.3

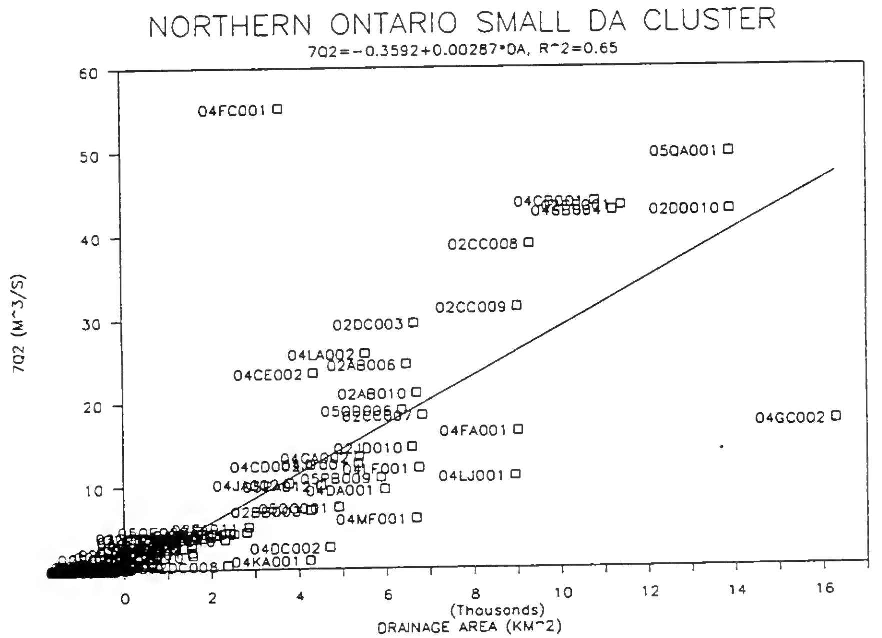


REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

INDEX METHOD NORTHERN ONTARIO, SUB-REGIONS ($7Q_2$)

FIGURE 4.4

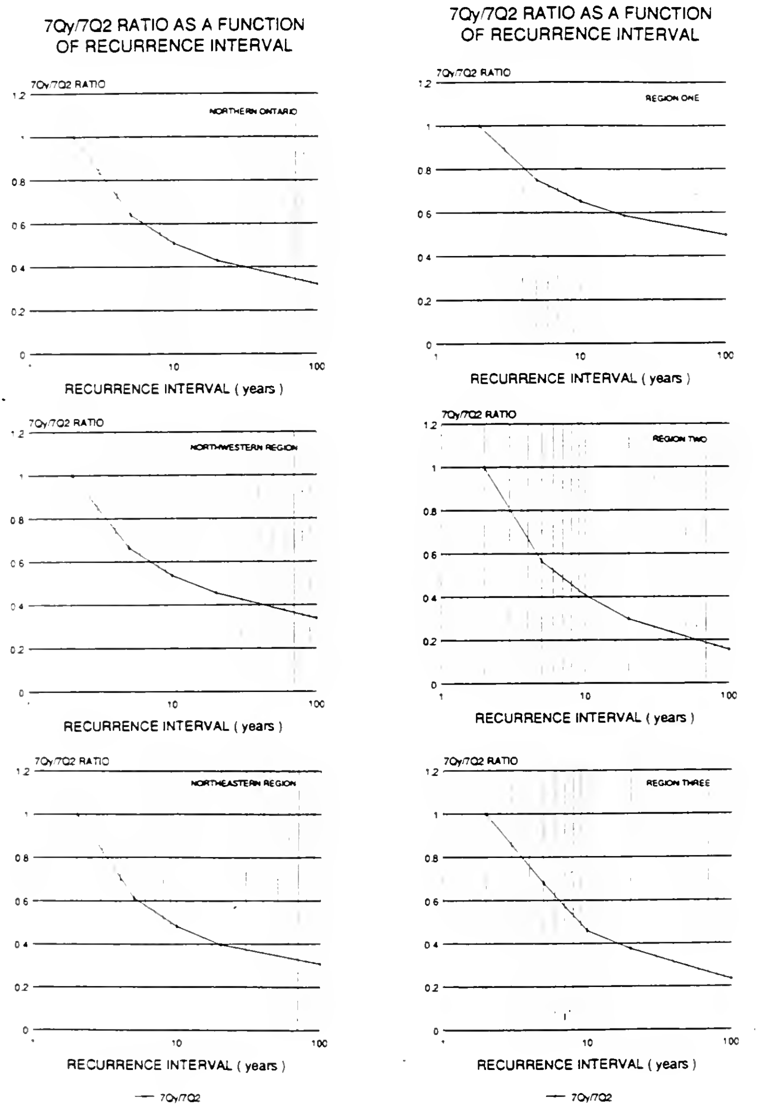




REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

INDEX METHOD HOMOGENEOUS REGIONS, CLUSTER ANALYSIS

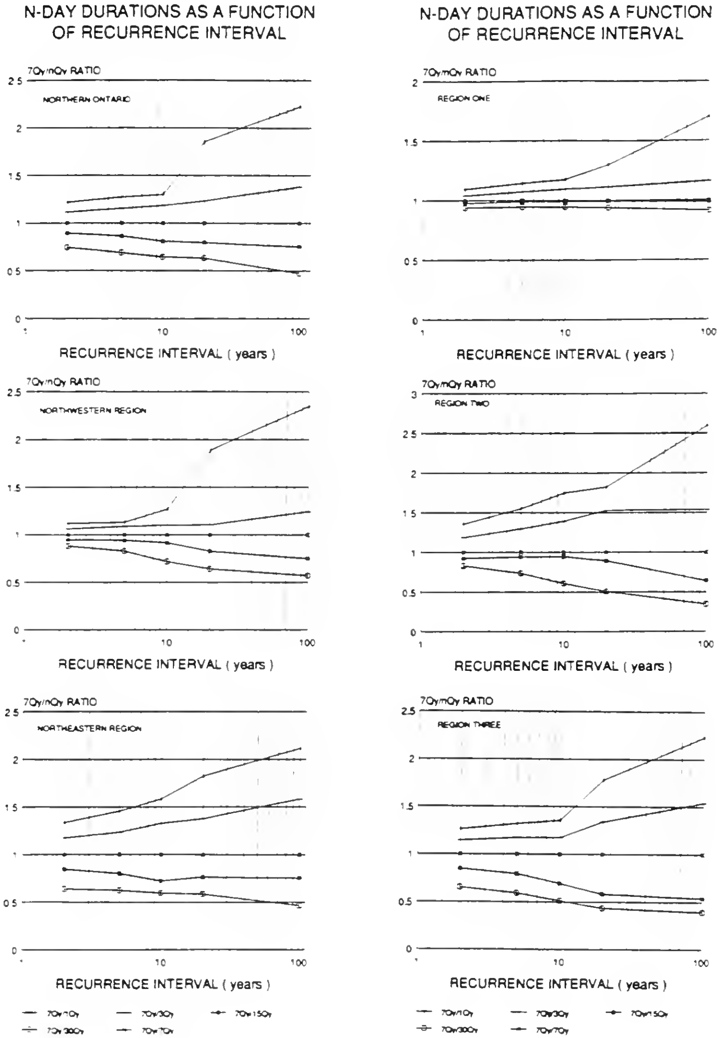
FIGURE 4.5



REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

INDEX METHOD RATIO OF $7Q_y$ TO $7Q_2$

FIGURE 4.6



REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

INDEX METHOD RATIO OF $7Q_y$ TO nQ_y

FIGURE 4.7

flow ratio as a function of $7Q_y$. The graphs of n-day low flows to 7-day low flows as well as the graph of 7-day y year recurrence ratio to $7Q_2$ low flows give some insight to the interrelationships between the various extreme value low flows.

The development and use of the Index Method indicates that it may be possible to utilize short periods of record to estimate $7Q_2$ low flows and then use the other graphs developed here to estimate low flows for other recurrence intervals (i.e. a few years of data may provide a reasonable estimate of $7Q_2$ which can then be extended by use of the graphs). For example, for Northern Ontario the correlation between the mean 7 day low flows extracted from the data for each station (7Q mean m^3/s) and the $7Q_2$ low flow values (m^3/s) determined for each station was found to take the following form:

$$7Q_2 = 0.47163 + 1.01008\ 7Q\ \text{mean} \qquad R^2 = 0.9984$$
$$n = 93$$

Finally the isoline map of $7Q_2$ could also be utilized to provide the index value from which other low flow statistics could be estimated using the procedures described above.

4.3.2 Regional Index/Frequency Distribution Method

The heterogeneity measure indicated that the three sub-regions of Northern Ontario are statistically homogeneous and, therefore, it is possible to establish a dimensionless regional frequency distribution for each region. According to the heterogeneity measure analysis,a useful by-product is that the three parameters of the Weibull III distribution have been regionalized. The parameters of Weibull III distribution for each sub-region are summarized in Table 4.1. These regional frequency curves could be used to estimate low flow characteristics for ungauged sites within the sub-regions, as described in Appendix E.

In order to use this method for predicting low flows for ungauged watersheds the first step is to estimate the index low flow. The index flow used herein is $7Q_2$, which can be estimated by using alternate procedures such as isolines, the regression method, graphical analysis for the region or short term measurements which may be available for the site. Next the regional parameters of the Weibull III distribution for the sub-region in which the site is located are identified from Table 4.1 and the following equation is used to estimate the regional quantile with recurrence interval.

$$\hat{q}_y = e + (u - e) \{ - \ln [1 - \frac{1}{y}] \}^{\frac{1}{a}} \tag{4 - 1}$$

TABLE 4.1
REGIONAL PARAMETERS FOR WEIBULL III DISTRIBUTION

Region	Duration (days)	a	e	u
1	1	1.952	0.341	1.136
	3	2.150	0.349	1.121
	7	1.272	0.403	1.105
	15	2.031	0.407	1.117
	30	1.095	0.424	1.116
2	1	1.362	0.090	1.281
	3	1.484	0.089	1.255
	7	1.772	0.050	1.190
	15	1.694	0.078	1.223
	30	1.842	0.104	1.197
3	1	1.400	0.194	1.241
	3	1.610	0.190	1.207
	7	1.580	0.221	1.203
	15	1.605	0.239	1.195
	30	1.503	0.259	1.205

where a, e, and u are obtained from Table 4.1.

The final step is to scale the low flow estimate to the site by the following equation:

$$Q_y = 7Q_2 \, \hat{q}_y \qquad (4 - 2)$$

The regional parameters of the Weibull III distribution for the 1, 3, 15, and 30 day durations were also calculated and are summarized in Table 4.1. This permits estimation of the low flow characteristics for the n-day duration for any occurrence interval.

4.4 Regression Method

4.4.1 General

Multiple linear regression equations take the following general form:

$$Q_y = a_0 + a_1Z_1 + a_2Z_2 + ... + a_nZ_n \qquad (4 - 3)$$

where Q_y = the dependent variable (e.g. $7Q_2$)

$Z_1 Z_2 ... Zn$ = the independent variables (e.g. physiographic and meteorologic watershed characteristics)

$a_0, a_1 ... a_n$ = regression coefficients

In order to obtain a more suitable cause and effect relationship, it is sometimes necessary to transform the data (eg. by taking logarithms, square roots, cubes, etc.). The transformations considered for this investigation are discussed in Section 4.4.3.

A number of regression procedures are available, including development of all possible equations, forward selection, backward selection, stagewise regression and stepwise regression. The stepwise regression procedure is generally recommended for use in practical applications (Draper and Smith, 1981) and was, therefore, adopted for the purposes of this investigation.

4.4.2 Methodology

The regression equations were developed utilizing the stepwise multiple linear regression procedure available in the Statistical Package for the Social Sciences (SPSS) (Nie, 1975). More specifically, the regression sub-program has been used and has the following special features:

1) Out of various procedures for selecting variables, including forward selection, backward elimination and the stepwise selection, the last one which is really a combination of backward and forward procedures, was adopted for this investigation as it is the most commonly used procedure for this type of study.
2) Variable selection - all independent variables can be stored and then only those variables desired for a particular analysis called up and used according to the desired form of the equation
3) Combination of variables - variable transformation and new variables may be computed from existing variables
4) Transformations - the variables may be transformed (e.g. square root, logarithmic, squared, etc.) in order to more nearly laniaries the relationships
5) Calculation of statistics - the SPSS regression package allows calculation of regression coefficients, statistics and residual statistics (difference between observed and calculated values). Also possible are scatter plots of residuals and statistical tests for residual analysis, etc.

The regression constant and regression coefficients are determined in order to minimize the sum of the square residuals. The residuals are the difference between the observed, dependent variable and the prediction by the regression equation. The SPSS program automatically includes those independent variables which meet the 95% confidence level based on the computed values of the F statistic. Only those variables which meet the specified level at any given step are retained in the regression equation and all those variables which fall below the specified level are deleted from the regression equation.

4.4.3 Transformed and Derived Parameters

The transformations used for this analysis were $\log_{10}$, square root, square and cube for selected meteorologic and physiographic parameters. The derived parameters used in this analysis are defined below:

1. Shape Factor 1, SF1 $= \dfrac{DA}{LNTH^2}$

2. Shape Factor 2, SF2 $= \dfrac{DA}{LNTH}$

The derived parameters SF1, and SF2, were also previously used for the investigation of low flow characteristics for Central and Southeastern Regions (Cumming Cockburn Limited, 1990).

TABLE 4.2(a)
SUMMARY OF CORRELATION ANALYSIS
7Q2 WITH TRANSFORMED PARAMETERS

Region	No. of Stations	SF1	SF2	MAP				MAS				MAR				EVA			
				MAP	MAP^0.5	MAP^2	Ln(MAP)	MAS	MAS^0.5	MAS^2	Ln(MAS)	MAR	MAR^0.5	MAR^2	Ln(MAR)	EVA	EVA^0.5	EVA^2	Ln(EVA)
N	93	0.040	0.850	−0.360	−0.400	−0.400	−0.400	−0.180	−0.220	−0.200	−0.230	−0.240	−0.240	−0.260	−0.210	−0.320	−0.310	−0.300	−0.310
NW	47	0.480	0.920	−0.310	−0.380	−0.400	−0.380	−0.220	−0.280	−0.260	−0.280	−0.200	−0.100	−0.160	−0.070	−0.150	−0.180	−0.170	−0.190
NE	46	−0.070	0.710	−0.420	−0.400	−0.370	−0.410	0.260	0.140	0.160	0.130	−0.210	−0.200	−0.220	−0.190	−0.530	−0.450	−0.440	−0.460
R1	28	0.590	0.940	−0.083	−0.075	0.098	−0.067	0.001	0.001	0.005	−0.002	0.140	0.120	0.170	0.110	0.290	−0.290	−0.280	−0.290
R2	14	0.640	0.960	0.450	0.460	2.450	0.460	0.030	−0.020	−0.030	−0.020	0.180	0.220	0.160	0.100	0.250	0.110	−0.100	−0.110
R3	51	0.300	0.970	−0.030	−0.040	−0.050	−0.040	−0.010	−0.020	−0.030	−0.020	−0.070	−0.050	−0.070	−0.040	−0.210	−0.210	−0.220	−0.200

Region	DA				BFI				LNTH				ACLS				5% Sign. Level
	DA	DA^0.5	DA^2	Ln(DA)	BFI	BFI^0.5	BFI^2	Ln(BFI)	LNTH	LNTH^0.5	LNTH^2	Ln(LNTH)	ACLS	ACLS^0.5	ACLS^2	LN(ACLS)	
N	0.840	0.850	0.780	0.660	0.240	0.290	0.300	0.280	0.500	0.510	0.390	0.460	−0.160	0.060	0.070	0.060	0.195
NW	0.860	0.900	0.850	0.770	0.230	0.270	0.270	0.270	0.390	0.460	0.360	0.460	−0.010	0.300	0.290	0.290	0.272
NE	0.880	0.760	0.860	0.570	0.140	0.160	0.170	0.150	0.610	0.510	0.380	0.440	−0.360	−0.260	−0.240	−0.250	0.287
R1	0.820	0.830	0.690	0.740	0.070	0.080	0.060	0.090	0.580	0.550	0.600	0.490	0.210	0.030	0.110	0.510	0.497
R2	0.990	0.980	0.940	0.910	−0.390	−0.420	−0.370	−0.410	0.420	0.450	0.330	0.460	−0.490	−0.160	−0.100	−0.180	0.468
R3	0.960	0.790	0.990	0.470	0.140	0.160	0.150	0.150	0.150	0.190	0.040	0.200	−0.130	0.140	0.120	0.130	0.260

TABLE 4.2(b)
SUMMARY OF CORRELATION ANALYSIS
7Q20 WITH TRANSFORMED PARAMETERS

Region	No. of Stations	SFI	SFII	MAP				MAS				MAR				EVA			
				MAP	MAP^0.5	MAP^2	Ln(MAP)	MAS	MAS^0.5	MAS^2	Ln(MAS)	MAR	MAR^0.5	MAR^2	Ln(MAR)	EVA	EVA^0.5	EVA^2	Ln(EVA)
N	99	-0.040	0.580	-0.340	-0.400	-0.390	-0.400	-0.050	-0.090	-0.070	-0.090	-0.160	-0.160	-0.190	-0.140	-0.430	-0.440	-0.430	-0.440
NW	52	0.160	0.680	-0.390	-0.570	-0.510	-0.510	-0.080	-0.150	-0.140	-0.150	-0.150	-0.030	-0.100	-0.020	-0.360	-0.450	-0.440	-0.460
NE	47	-0.070	0.580	-0.430	-0.410	-0.380	-0.420	0.060	0.150	0.160	0.140	-0.170	-0.130	-0.150	-0.120	-0.540	-0.480	-0.470	-0.490
R1	14	0.580	0.950	0.073	0.060	0.090	0.060	0.051	0.050	0.060	0.050	0.140	0.170	0.220	0.150	-0.270	-0.270	-0.270	-0.270
R2	16	0.450	0.830	-0.200	-0.200	-0.200	-0.200	0.160	0.160	0.160	0.160	0.090	0.110	0.010	0.150	0.330	0.320	0.320	0.320
R3	55	0.300	0.950	-0.040	-0.050	-0.060	-0.050	0.020	-0.030	-0.040	-0.030	-0.050	0.060	-0.060	-0.040	-0.210	-0.220	-0.230	-0.210

Region	DA				BFI				LNTH				ACLS				5% Sign. Level
	DA	DA^0.5	DA^2	Ln(DA)	BFI	BFI^0.5	BFI^2	Ln(BFI)	LNTH	LNTH^0.5	LNTH^2	Ln(LNTH)	ACLS	ACLS^0.5	ACLS^2	LN(ACLS)	
N	0.830	0.740	0.690	0.580	0.210	0.280	0.290	0.270	0.570	0.530	0.470	0.460	-0.240	-0.010	0.010	0.010	0.195
NW	0.950	0.910	0.880	0.790	0.280	0.360	0.390	0.350	0.590	0.650	0.580	0.610	-0.080	0.370	0.370	0.350	0.272
NE	0.820	0.670	0.860	0.470	0.140	0.160	0.160	0.160	0.560	0.450	0.370	0.370	-0.380	-0.300	-0.280	-0.290	0.287
R1	0.770	0.780	0.650	0.700	0.040	0.040	0.030	0.040	0.530	0.500	0.540	0.450	-0.220	0.520	0.430	0.530	0.497
R2	0.950	0.920	0.970	0.830	0.240	-0.240	-0.230	-0.230	0.380	0.400	0.330	0.400	-0.600	0.010	0.080	-0.010	0.468
R3	0.960	0.750	0.990	0.430	0.160	0.160	0.160	0.160	0.150	0.170	0.040	0.180	0.150	0.120	0.100	0.120	0.260

4.4.4 Simple Correlation of Parameters

Simple correlations between independent and dependent parameters were examined to screen parameters for input to subsequent regression analyses.

In general it was found that the independent parameters which are most highly correlated to low flows are DA, EVA, LNTH, and MAR. (Some other parameters were found to be inter-correlated with these.) The data transforms also indicated that the square and the square root of the drainage area remained highly correlated with the low flow statistics. It was also found that the Regulation Code (RN) is not significantly correlated with low flows.

4.4.5 Regression Equation Development

A large number (several hundred) of preliminary regression equations were developed in order to predict the $7Q_2$ and $7Q_{20}$ low flows as a function of basin physiographic and hydrometeorologic parameters.

The results indicated that the most significant parameters for predicting low flow characteristics in Northern Ontario are drainage area (DA), stream length (LNTH) and the mean annual runoff (MAR).

The final regression equations are presented in Table 4.3 for the study area.

However, while the R^2 values are generally high it is also noted that the standard error of estimate (as a percentage) is also large in some cases. This indicates that care should be taken in application of the Regression Method for prediction of low flows.

4.4.6 Regression Equations For Statistical Homogeneous Regions

Regression equations developed for the various sub-regions are also compared to those developed for the Northeastern and Northwestern Regions in Table 4.3. The comparisons indicate some improvement in the standard error of estimate for the equations developed for Regions 1, 2, and 3 compared to the equations for other areas.

TABLE 4.3

SUMMARY OF REGRESSION ANALYSIS

$$Y = A_0 + A_1\,DA + A_1^{\,1}\,DA^{1/2} + A_1^{\,2}\,DA^2 + A_2\,LNTH + A_2^{\,1}\,LNTH^{1/2} + A_3 * MAR + A_3^{\,1}\,MAR^2$$

Region	Independent Parameters								Number of Stations	SE	R^2
	A_0	A_1	$A_1^{\,1}$	$A_1^{\,2}$	A_2	$A_2^{\,1}$	A_3	$A_3^{\,1}$			
Northwestern											
$7Q_2$	23.779	0.00232				-1.81			47	21.16	0.76
$7Q_{20}$	-1.899		0.317			-0.909			47	9.04	0.82
Northeastern											
$7Q_2$	6.549	0.00436			-0.123				46	17.81	0.81
$7Q_{20}$	3.26	0.00277			-0.0797				46	14.91	0.70
Region One											
$7Q_2$	-35.766		0.8628			-4.130		0.000353	28	10.21	0.89
$7Q_{20}$	-25.718		0.5587			-2.89		0.000272	28	8.63	0.87
Region Two											
$7Q_2$	21.65	0.00337				-4.791	0.1088		14	19.34	0.85
$7Q_{20}$	8.124	0.00125				-0.796	-0.0104		14	7.90	0.88
Region Three											
$7Q_2$	7.506			$1.581*10^{-7}$		0.5491	-0.0156		51	3.78	0.98
$7Q_{20}$	0.4185			$9.777*10^{-8}$		0.3403	-0.0055		51	1.62	0.98
Large DA Group ($DA > 17{,}000\ Km^2$)											
$7Q_2$	-127.91	0.00351			-0.461		0.7219		15	31.17	0.91
$7Q_{20}$	-146.31	0.002217			-0.222		0.5726		15	22.73	0.89
Small DA Group ($DA < 17{,}000\ Km^2$)											
$7Q_2$	-3.15	0.00323			-0.01898		0.00756		78	6.07	0.87
$7Q_{20}$	-2.45	0.0016			-0.0021		0.0047		78	4.70	0.86

4.4.7 Sensitivity Analysis

Some error in estimating watershed characteristics (eg. DA, LNTH and MAR) could occur when predicting low flows for ungauged watersheds using the regression equations. Therefore, a sensitivity analysis was undertaken using the following equation:

$$\epsilon = \left[\frac{7Q_y - 7Q_y}{7Q_y}\right] x\ 100 \qquad (4 - 4)$$

where $y = 2$ or 20 year recurrence interval

ε = resulting error in percent

For the purpose of this analysis the base value $7Q_y$ was calculated using the mean value of the independent parameter in the indicated region. The $7Q'_y$ was then calculated by changing one parameter to a selected percentage of the real value (10% for example) while keeping all of the other parameters constant.

A summary of the sensitivity testing results is given in Table 4.4. In general, changes in drainage area were directly reflected in the low flow estimate, while ± 10% changes in the LNTH parameter resulted in smaller changes in low flow. It was also found that small changes in MAR give large changes in low flow for the Small and Large Drainage Area Groups and for Sub-Region One. Generally, the use of Sub-Regions 1, 2, and 3 appears to be reasonable, although care should be taken in applying and interpreting the results obtained from the regression equations.

4.5 Station Proration

In the past it has been common practice to prorate unit flows from nearby gauged watersheds to estimate low flows for ungauged watersheds. This is generally done by experienced hydrologists who have a good understanding of local stream characteristics and other factors within the region (i.e. diversions and regulation, etc.).

For assessment of this method, the $7Q_2$ and $7Q_{20}$ low flow characteristics were determined for stations in the region and summarized in Figures 3.1 and 3.2 (in pocket) and Table 3.8.

TABLE 4.4
RESULTS OF SENSITIVITY ANALYSIS OF THE INDEPENDENT PARAMETERS

Region	Low Flows	ε (%)		
		DA*	LNTH*	MAR*
Northwestern	$7Q_2$ $7Q_{20}$	-9.30, 9.30 -8.31, 7.90	3.99, -3.79 2.71, -2.58	N/A N/A
Northeastern	$7Q_2$ $7Q_{20}$	-13.13, 13.13 -14.49, 14.49	6.83, -6.83 7.69, -7.69	N/A N/A
Region One	$7Q_2$ $7Q_{20}$	-10.44, 9.93 -10.89, 10.36	5.55, -5.28 6.33, 6.02	-12.64, 13.97 -15.87, 17.54
Region Two	$7Q_2$ $7Q_{20}$	-9.91, 9.91 -11.67, 11.67	5.80, -5.52 3.06, -2.91	-6.21, 6.21 1.88, -1.88
Region Three	$7Q_2$ $7Q_{20}$	-4.28, 4.73 -6.28, 6.94	-3.42, 3.25 -5.03, 4.79	9.26, -9.27 7.75, -7.76
Large DA Group	$7Q_2$ $7Q_{20}$	-11.40, 11.40 -13.05, 13.05	9.70, -9.70 8.47, -8.47	-18.57, 18.57 -26.7, 26.7
Small DA Group	$7Q_2$ $7Q_{20}$	-12.49, 12.49 -11.83, 11.83	2.21, -2.21 0.47, -0.47	-3.18, 3.18 -3.78, 3.78

*Note: ± 10% of error assumed independently for these variables.

To estimate low flows at a location between sites located on Figures 3.1 and 3.2, the reciprocal distance can be used in the proration (i.e. the distance to nearby gauges would be estimated and the unit low flow values are then weighted by the reciprocal of the distance as a percentage (of the total distances) and then averaged).

4.6 Summary

The general procedures for estimating low flows at ungauged sites in Northern Ontario are summarized in Figure 4.8.

Of the four low flow estimating methods, the Mapped Isolines and the Index Method are the easiest to use. The relative prediction accuracy of all these methods is evaluated and discussed in Section 5.0. The Station Proration Method has been included due to its widespread use and to evaluate whether the alternate techniques provide improved estimation of low flow characteristics.

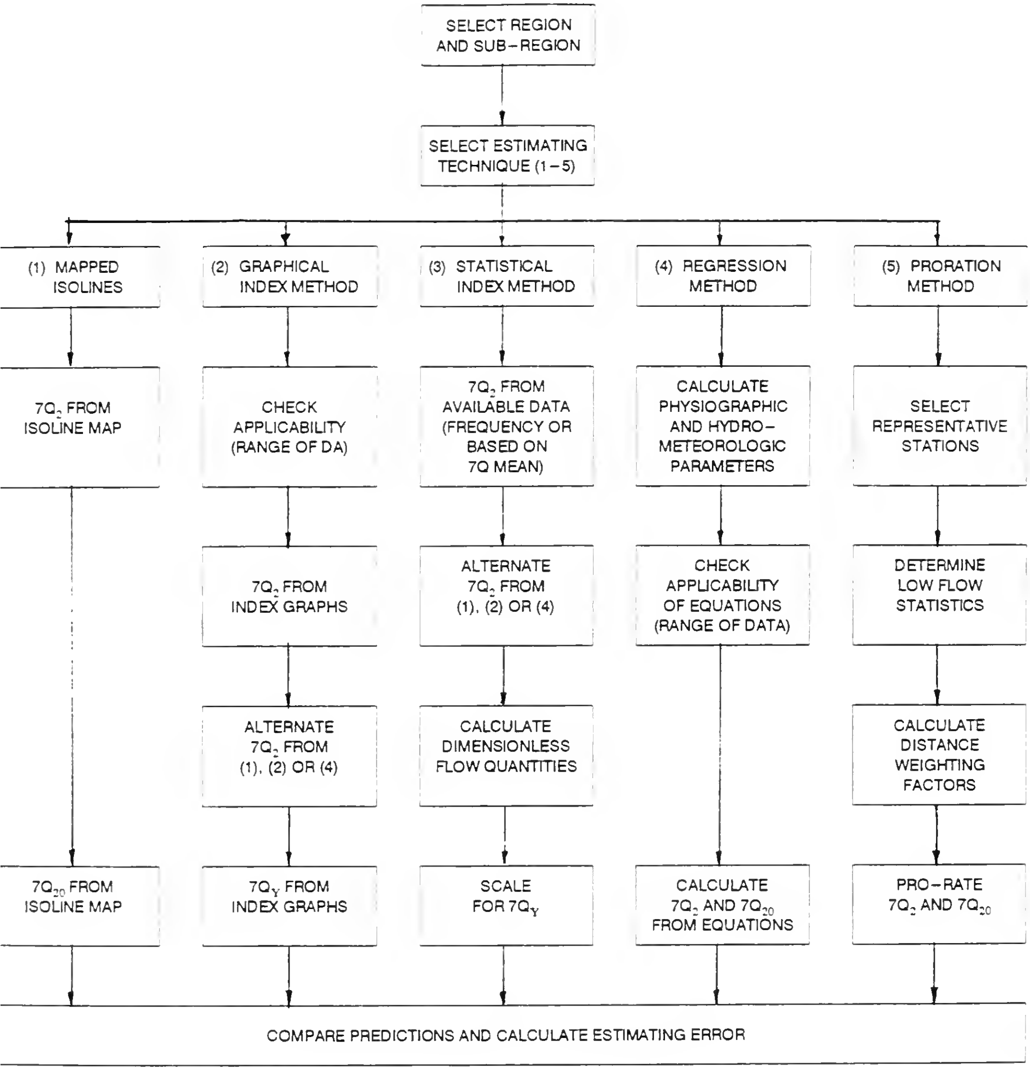
The first step in estimating low flow characteristics is to identify the region in which the site is located.

To use the mapped isoline method, the unit low flow value is extracted from the relevant map. The drainage area in km^2 is then multiplied by the unit low flow $7Q_2$ ($7Q_{20}$) to obtain the appropriate estimate.

To apply the index method, one should follow the procedures described in Section 4.3 which describes both the graphical technique and index method based on regional statistics.

Alternative equations are also available for regression estimates, based on either large or small regions (see Section 4.4). It is likely that equations for Regions 1, 2, or 3 will be preferred.

Finally it is suggested no single method should be used in isolation due to significant variations in watershed and low flow characteristics in Northern Ontario. The various methods and estimating methods should be compared to obtain an appropriate low flow estimate.



REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

FLOW CHART OF LOW FLOW ESTIMATION PROCEDURES

FIGURE 4.8

5.0 TESTING PREDICTION METHODS

5.1 General

The relative prediction accuracy of the low flow prediction methods described in Section 4.0 was examined by application to a total of 21 stations for Northern Ontario (12 in the Northwestern and 9 in the Northeastern Region, respectively). The hydrometric records available at these stations were not previously included in the development of the regional low flow estimation techniques, and therefore, it was possible to compare the at station estimates of low flow characteristics to the estimates provided by the regional techniques.

For ease of reference, the various estimating procedures are referred to as follows:

1) Method 1: Mapped Isolines;
2) Method 2: Graphical Index Method;
3) Method 3: Statistical Index Method;
4) Method 4: Regression Method; and
5) Method 5: Proration Method.

5.2 Test Stations

The test stations all have at least 10 years of record, and are active within the last 5 years. Stations were selected spatially to cover the complete region and with a range of watershed characteristics similar to the overall data base. The data base for these stations is summarized in Tables 5.1(a) and (b) for the Northwestern and Northeastern regions, respectively.

5.3 Goodness of Fit

To test the goodness of fit, the Nash-Sutcliffe (1970) model efficiency parameter (N.S.R.^{2}) was utilized. The goodness of fit statistic is calculated by the following relationship:

$$N.S.R.^2 = 1 - \frac{\sum_{i=1}^{n} (Q_s - Q_o)^2}{\sum_{i=1}^{n} (Q_o - Q_m)^2} \qquad (5 - 1)$$

TABLE 5.1(a)
STATIONS SELECTED FOR TESTING
NORTHWESTERN REGION

Plotting Code	Station No.	Regulation Code	Sub-Region Code	No. of Years	Period of Record	MAP (mm)	MAS (mm)	MAR (mm)	EVA (mm)	DA (km^2)	BFI	LNTH (km)	ACLS (%)	7Q2 (m^3/s)	7Q20 (m^3/s)
1	02AB017	0	3	11	80-90	785	240	392	500	210	0.37	25.0	0	0.17	0.07
2	02BA003	0	3	19	72-90	850	230	365	490	1320	0.62	128.5	69	2.79	2.20
3	04DB001	0	1	25	66-90	610	230	328	360	7950	0.94	304.2	100	16.26	11.21
4	04GF001	0	1	18	70-90	710	280	380	400	1890	0.77	145.0	72	1.23	0.15
5	04FA003	0	1	25	66-90	690	260	389	400	4900	0.77	273.1	30	6.38	3.54
6	04JC003	0	1	37	50-87	810	300	347	415	3290	0.75	107.7	1	6.8	3.71
7	04GB005	0	1	21	68-90	745	300	310	390	1170	0.76	44.8	45	3.73	0.88
8	05PA006	0	2	70	21-90	750	220	255	510	13400	0.99	196.9	100	34.05	20.74
9	05PB018	0	2	12	78-90	800	220	244	505	332	0.84	80.5	40	1.16	0.48
10	05QA002	0	2	70	21-90	790	220	287	500	6230	0.98	54.3	90	21.22	9.01
11	05PB015	0	2	18	63-90	665	190	180	468	443	0.80	56.4	80	0.39	0.01
12	05RC001	0	2	11	80-90	690	190	235	450	5730	0.83	191.7	70	8.26	4.85

TABLE 5.1(b)
STATIONS SELECTED FOR TESTING
NORTHEASTERN REGION

Plotting Code	Station No.	Regulation Code	Sub-Region Code	No. of Years	Period of Record	MAP (mm)	MAS (mm)	MAR (mm)	EVA (mm)	DA (km^2)	BFI	LNTH (km)	ACLS (%)	7Q2 (m^3/s)	7Q20 (m^3/s)
13	02BF005	0	3	11	80-90	905	300	826	520	11.5	0.52	20.5	50	0.01	0
14	02CB003	1	3	11	80-90	850	290	363	500	1440.0	0.56	40.6	30	3.10	1.69
15	02CD003	0	3	14	77-90	900	255	500	500	319.0	0.69	5.0	100	0.75	0.01
16	02CF011	0	3	20	70-90	800	260	240	490	704.0	0.63	57.0	87	2.36	1.26
17	02CF013	0	3	10	81-90	800	255	413	490	40.6	0.49	35.0	50	0.03	0
18	02DD008	0	3	27	56-82	860	270	576	500	90.4	0.41	34.3	28	0.13	0.03
19	02DD015	0	3	17	74-90	880	270	537	500	106.0	0.53	10.5	0	0.11	0.04
20	02EB013	0	3	18	73-90	820	280	380	500	593.0	0.62	44.5	80	1.90	1.027
21	04KA002	0	1	15	76-90	710	265	360	370	133.0	0.65	46.8	50	0.04	0.01

where Q_o and Q_s are the observed and simulated discharges, and Q_m is the mean of the observed discharges and n is the total number of test stations (21 in this case) (N.S.R.^{2} = 1.0 for a perfect comparison of actual and estimated values).

The "observed" low flows ($7Q_2$ and $7Q_{20}$) were determined by undertaking a single station low flow frequency analysis for each of the stations listed in Table 5.1. (It is recognized that these flows will also contain estimating error, but it is assumed that the comparison will provide a means of comparing the relative accuracy of the various techniques). Each prediction method was then utilized in turn to provide a simulated low flow estimate. Graphical and statistical (N.S.R.^{2}) comparisons were then made for each method as discussed in Section 5.4.

5.4 Testing Results

Testing was initially undertaken applying the procedures developed for the Northeastern and Northwestern Regions and for the three Sub-Regions previously identified. The overall testing results are summarized in Table 5.2. It is evident from Table 5.2 that application of the techniques, which were developed for the three Sub-Regions, provided better low flow flow estimates compared to the techniques for the NE/NW regions. (However, estimates by methods developed for the two sub-regions could be used for checking calculations by other methods). The more detailed discussion of testing results in the following sections focuses on testing using the procedures developed for Regions 1, 2, and 3 in Northern Ontario.

5.4.1 Testing of Isoline Method

The isoline maps were used to predict flows for each of the test stations (see Figures 4.1 and 4.2). The $7Q_2$ and $7Q_{20}$ unit low flows were estimated for the test stations by interpolating the values between the contour lines at the location of interest. The results of this analysis are presented in Figure 5.1.

The N.S.R^2 for all test stations for $7Q_2$ and $7Q_{20}$ is 0.97 and 0.96, respectively, which is reflected in the results on Figures 5.1.

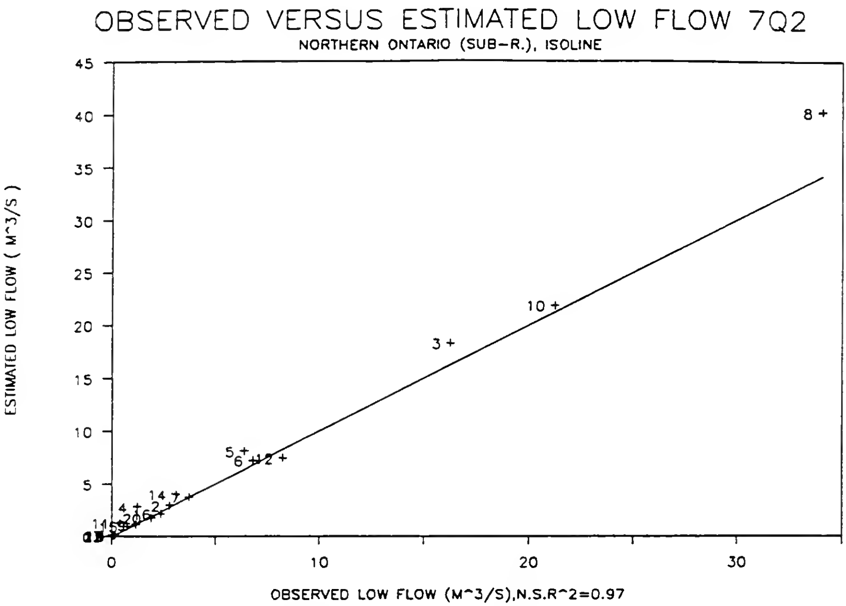
It is generally concluded that, compared to the other techniques, the isoline method is a robust method which produced good estimates of the $7Q_2$ and $7Q_{20}$ low flows.

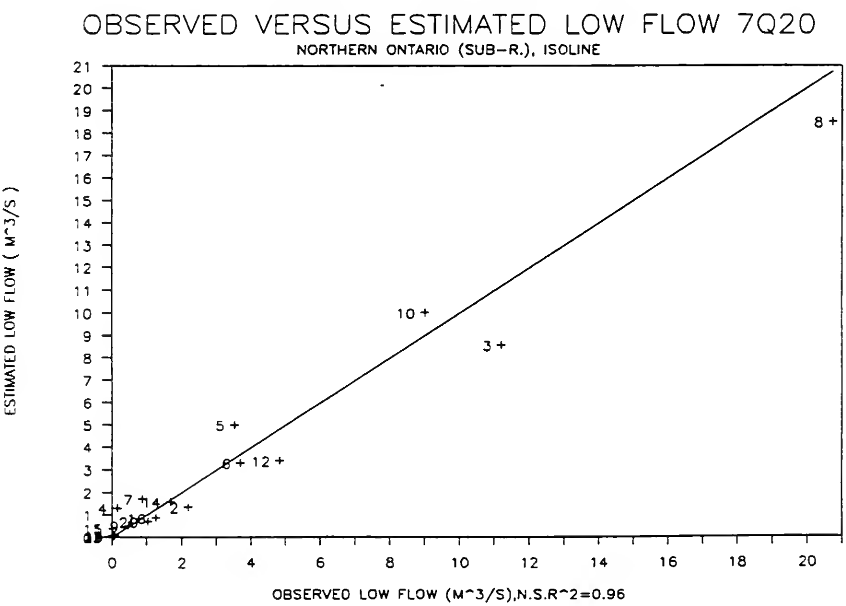
TABLE 5.2
SUMMARY OF TESTING RESULTS (N.S.R.^{2})

Way of Regionalization	Method 1 Isoline		Method 2 Index		Method 3 Index 2**		Method 4 Regression		Method 5 Proration	
	$7Q_2$	$7Q_{20}$	$7Q_2$	$7Q_{20}$	$7Q_2$	$7Q_{20}$	$7Q_2$	$7Q_{20}$	$7Q_2$	$7Q_{20}$
NW/NE	0.97	0.96	0.86	0.82	N/A	N/A	0.57	0.85	0.92	0.48
Sub-regions	0.97	0.96	0.92	0.87	0.97	0.92	0.79	0.87	0.92	0.48

** Index from isoline method

Note: No difference for isoline method and Station Proration Method in different regions since both methods are spatially determined.





CCL	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	METHOD 1 - TESTING ISOLINE METHOD FIGURE 5.1

5.4.2 Testing of Index Method

Index values for $7Q_2$ were derived for each station by using Figure 4.3, 4.4, and 4.5. The results of the comparison are summarized on Figure 5.2.

The $7Q_{20}$ value was then calculated with reference to Figure 4.6.

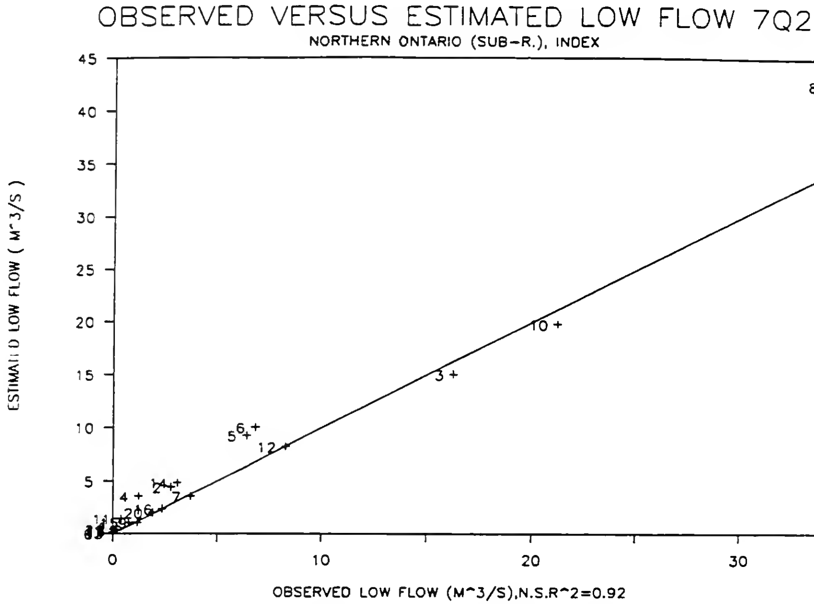
Application of the index method resulted in N.S.R.^{2} values of 0.92 and 0.87 for $7Q_2$ and $7Q_{20}$ respectively. Generally speaking, the index method gives a better prediction for $7Q_2$ than for $7Q_{20}$. However, overall, the comparison with the isoline method indicates that it might be preferable to determine the $7Q_2$ index value from the isoline maps rather than the drainage area index relationships. (When this was done, the N.S.R.^{2} value for the index method changed to 0.90 for $7Q_{20}$.

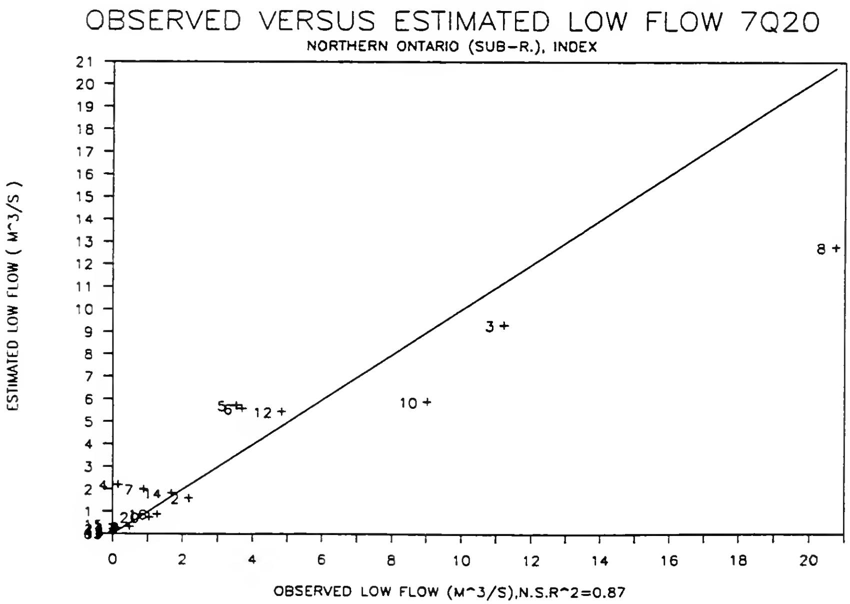
5.4.3 Statistical Index Method (Regional Index Low Flow Frequency Distribution Method)

This method uses an index low flow and the characteristics of a regional frequency distribution to estimate $7Q_{20}$. The method is described in Section 4.3.2. The statistics of the regional frequency distribution are summarized in Table 4.1 for Regions 1, 2, and 3, and were used together with various index method estimates of $7Q_2$ in order to estimate $7Q_{20}$. Results of estimates using the isoline map for $7Q_2$ are summarized in Table 5.2. However, other index method estimates were also undertaken for the test stations:

1) $7Q_2$ from isoline map; N.S.R^2 = 0.92 for $7Q_{20}$; see Figure 5.3 (a)
2) $7Q_2$ from graphical index method; N.S.R.^{2} = 0.89 for $7Q_{20}$; see Figure 5.3(b)
3) $7Q_2$ from station mean 7 day low flow; N.S.R.^{2} = 0.996 for $7Q_2$; N.S.R^2 = 0.97 for $7Q_{20}$; see Figure 5.3 (c)
4) $7Q_2$ from test station frequency analysis; N.S.R^2 = 0.96 for $7Q_{20}$; see Figure 5.3 (d)

The use of available data at the test stations improved the overall estimates of $7Q_{20}$. This implies that the use of available measurements (either directly or obtained by correlation with other long term data) can significantly improve low estimates by the statistical index method. Therefore, ongoing collection of hydrometric data at a large number of locations in Northern Ontario should be encouraged (One strategy could be to collect enough short term data to obtain a reasonable estimate of the mean 7 day low value. Once this data is obtained the data collection platform could be moved to another location to maximize the use of resources.)

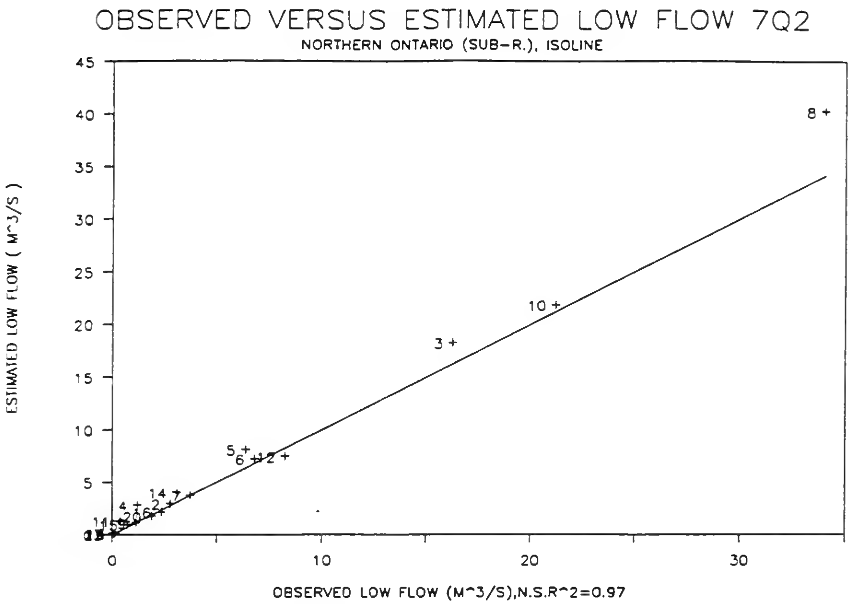


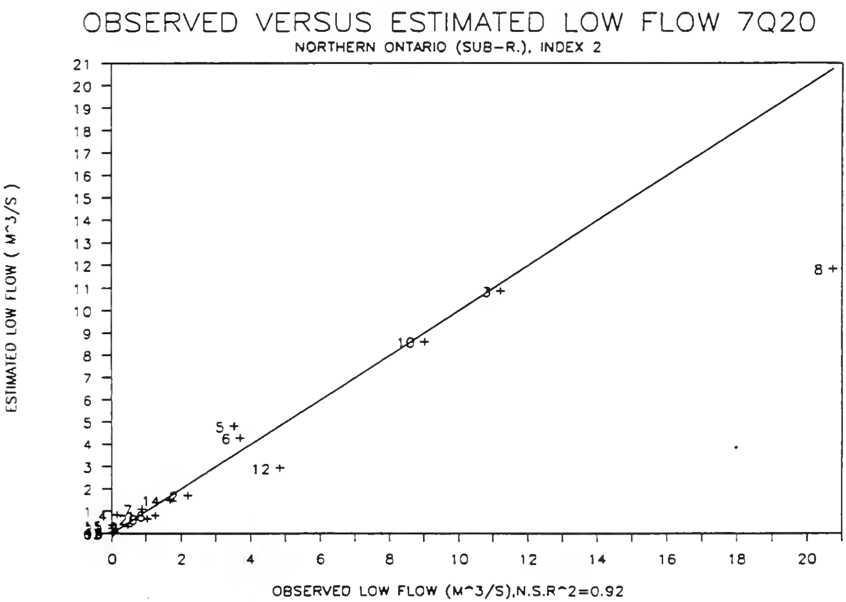


REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 2 - TESTING GRAPHICAL INDEX METHOD

FIGURE 5.2

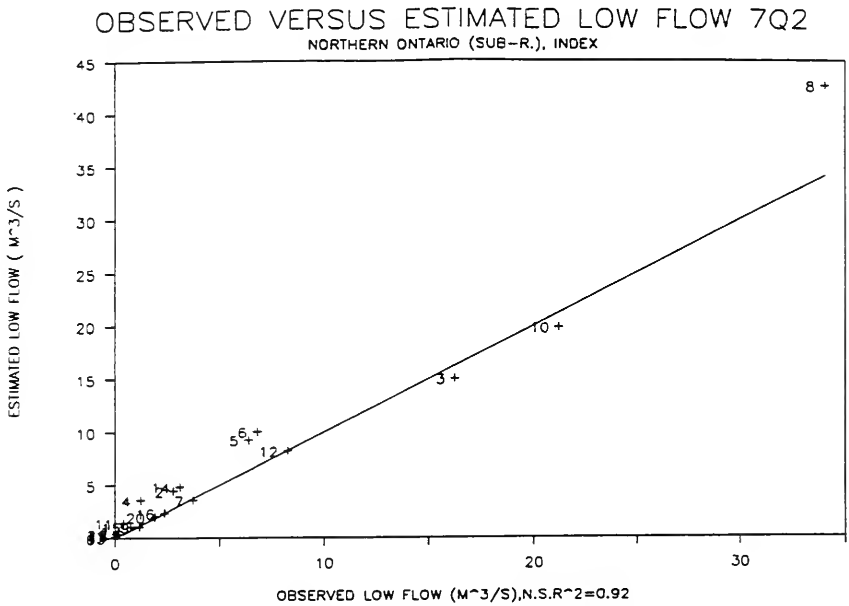


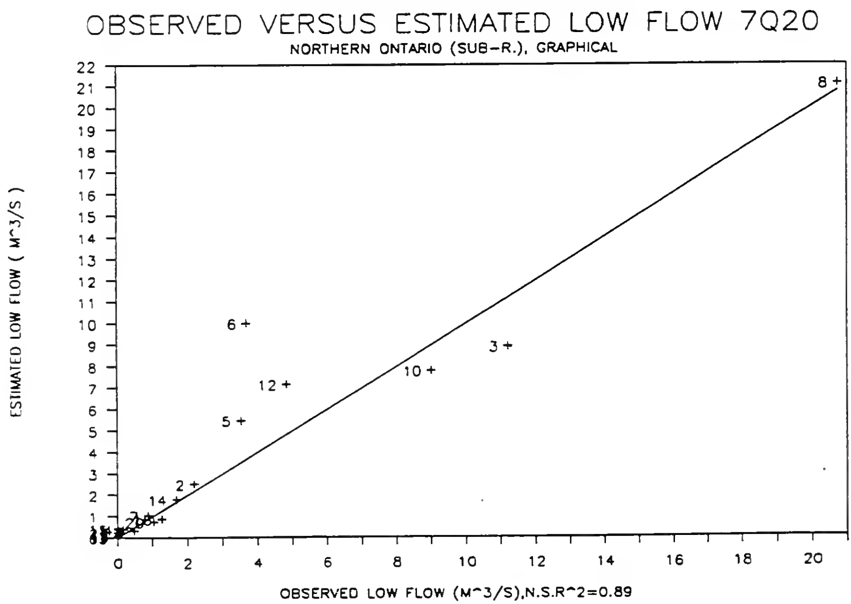


REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 3 - TESTING STATISTICAL INDEX METHOD

FIGURE 5.3(a)





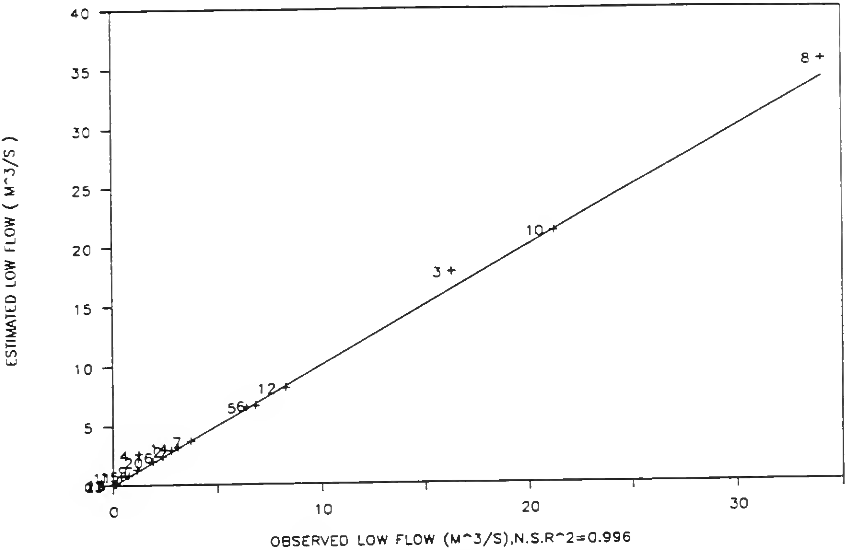
REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 3 - TESTING STATISTICAL INDEX METHOD

FIGURE 5.3(b)

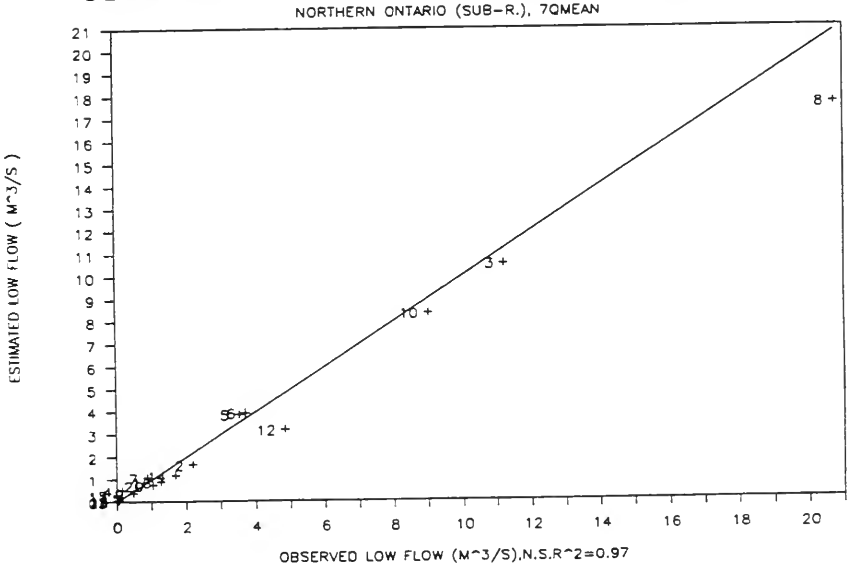
OBSERVED VERSUS ESTIMATED LOW FLOW 7Q2

NORTHERN ONTARIO (SUB-R.), 7QMEAN



OBSERVED VERSUS ESTIMATED LOW FLOW 7Q20

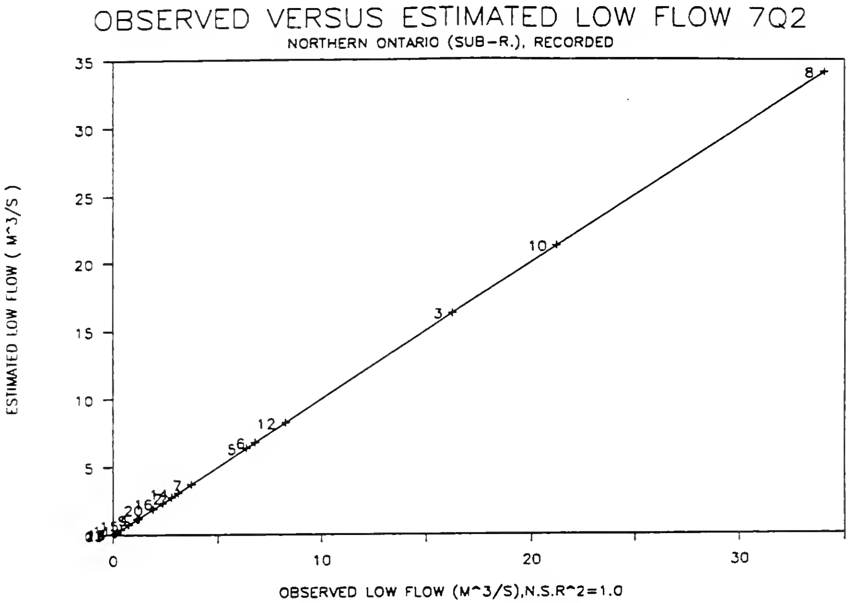
NORTHERN ONTARIO (SUB-R.), 7QMEAN

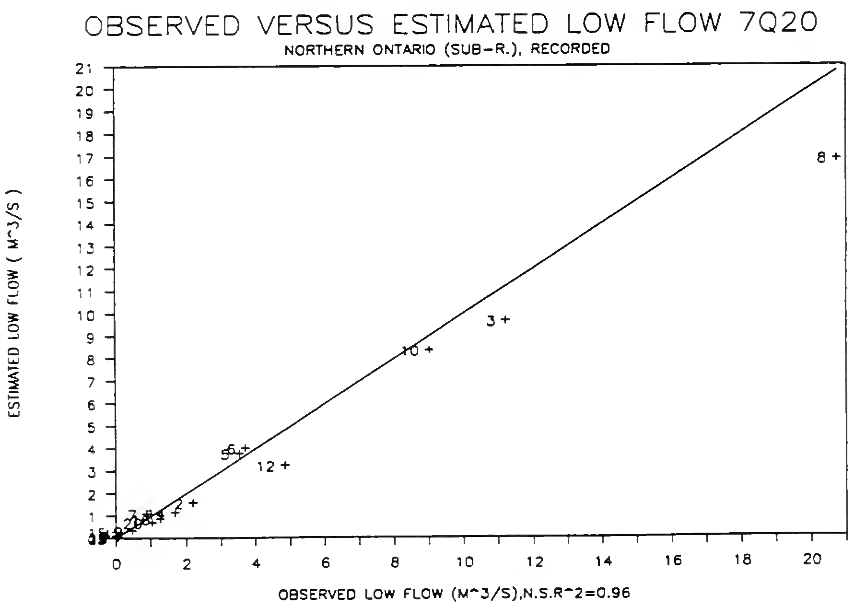


REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 3 - TESTING STATISTICAL INDEX METHOD

FIGURE 5.3(c)





REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 3 - TESTING STATISTICAL INDEX METHOD

FIGURE 5.3(d)

The overall accuracy of this prediction method depends, somewhat, on how well the index low flow is estimated. For example, if the index flow can be estimated from the locally available date base, then the overall prediction accuracy for $7Q_{20}$ can be improved.

5.4.4 Testing of Regression Method

The Sub-Regions 1, 2, and 3 and regression equations summarized in Table 4.3 were used to estimate low flows at the test stations. A comparison of the observed and estimated low flows is shown in Figure 5.4 for $7Q_2$ and $7Q_{20}$. Comparison of the overall regression results to the other prediction techniques indicates that, in general, the other techniques (except for proration) provide better low flow estimates for $7Q_{20}$. This is somewhat disappointing since the present regression equations were obtained after several hundred iterations and a great deal of effort trying various transformations and derived forms of parameters. Even after this effort, a significant improvement in low flow prediction results was not obtained using multiple linear regression.

5.4.5 Testing of Station Proration Method

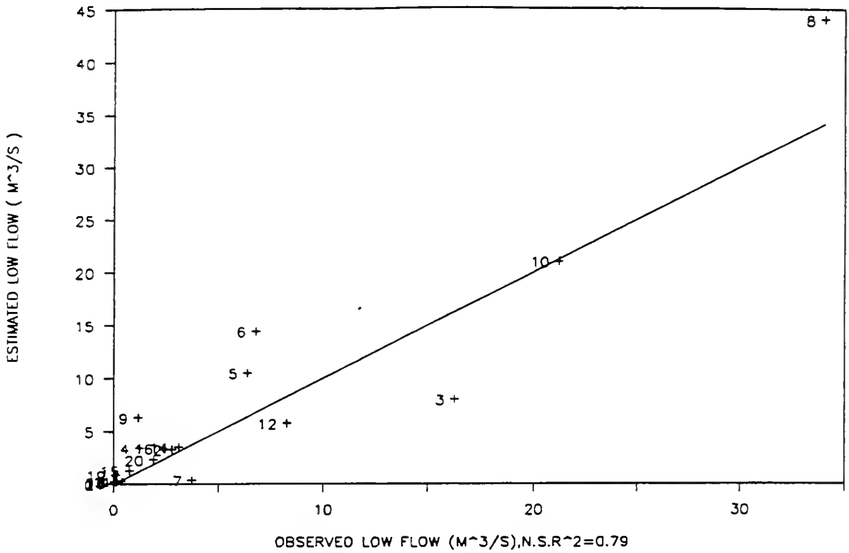
The method of reciprocal distance was used in obtaining pro-rated low flow estimates (i.e. the distances from the test stations to nearby gauges were measured and the weighted average of the unit low flows as determined from Figure 3.1 and 3.2 was estimated for the test stations by using the reciprocal of distances to nearby stations and their observed unit area low flows). The results are summarized on Figure 5.5.

It is also noted that over half of the 21 test stations are located on the same river system from which some of the low flow statistics are pro-rated. Therefore, better results might be expected from this method.

In this case, the overall prediction of $7Q_2$ was found to be fairly good while that for $7Q_{20}$ is considered to be poor. N.S.R^2 statistics are 0.92 and 0.48, respectively. It was also found that low flow estimates were better for stations in close proximity to hydrometric measurements (the more data/stations the better the estimate). In general, the use of the station proration method appears to provide poor estimates of regional low flows compared to the other methods.

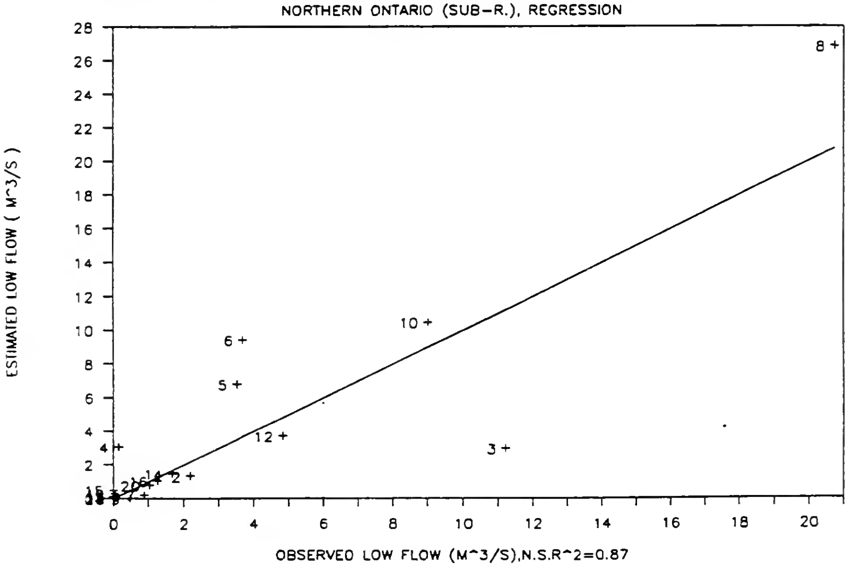
OBSERVED VERSUS ESTIMATED LOW FLOW 7Q2

NORTHERN ONTARIO (SUB-R.), REGRESSION



OBSERVED VERSUS ESTIMATED LOW FLOW 7Q20

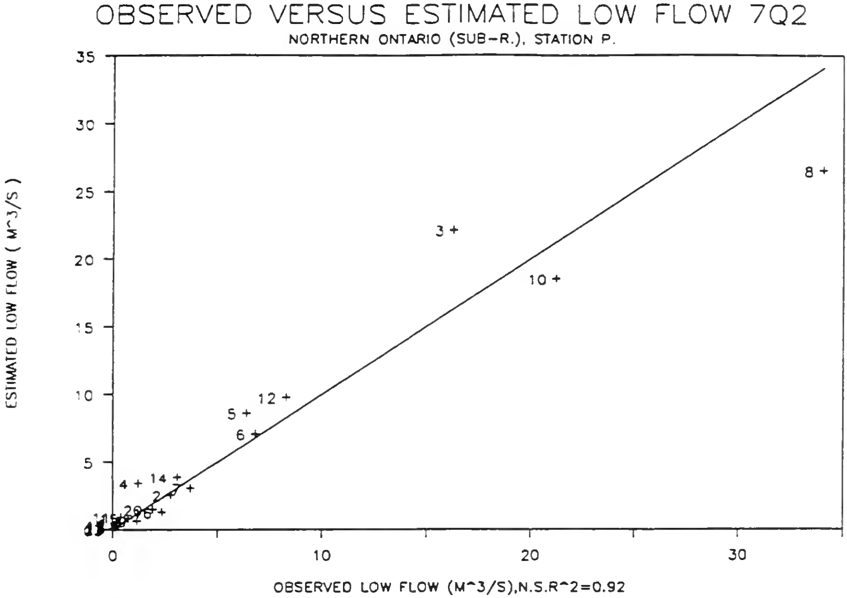
NORTHERN ONTARIO (SUB-R.), REGRESSION

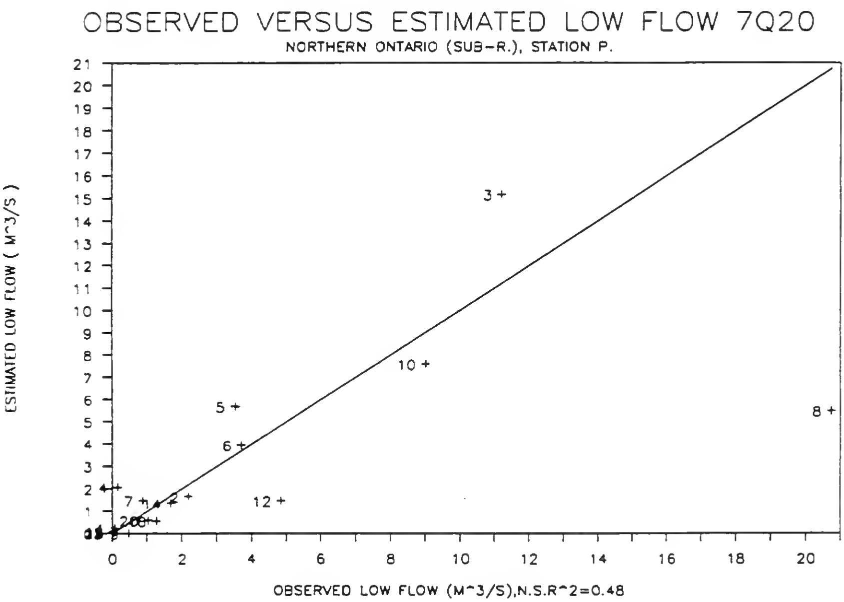


REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 4 - TESTING REGRESSION METHOD

FIGURE 5.4





REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

METHOD 5 - TESTING PRORATION METHOD

FIGURE 5.5

5.5 Summary

A sub-set of 21 stations was reserved for testing the following low flow prediction methods:

1) Mapped Isolines;
2) Graphical Index Method;
3) Statistical Index Method;
4) Regression Method; and
5) Proration Method.

The prediction methods were applied using the procedures outlined in Figure 4.8.

The prediction methods developed for the three sub-regions (Region 1, Region 2, and Region 3) provided better overall accuracy compared to the methods developed for two sub-regions (Northeastern and Northwestern Ontario); however, the method for the latter regions could be used for the purposes of checking low flow estimates by other techniques. (The isoline and index methods produced the best results). The use of the sub-regions applies to application of the index and regression methods (2, 3, and 4 above).

Table 5.3 gives an overall summary of the ability of the prediction methods to calculate the mean $7Q_2$, $7Q_{20}$ and associated unit low flows for the 21 test stations (i.e the average $7Q_2$ for the 21 test stations was found to be 2.90 m^3/s with a corresponding unit runoff value of .0012 $m^3/s/km^2$ (this is low compared to other stations in Northern Ontario - eg. refer to Table 3.6). The corresponding values predicted by the isoline method were 2.76 m^3/s and .0012 $m^3/s/km^2$). The relative accuracy of the various methods are also approximately ranked in Table 5.4.

Even though the N.S.R.^{2} statistic may be high, poor low flow estimates can occur at individual stations. This is observed to occur for all methods (for example see Figure 5.1 to 5.5, from which it is evident that significant errors occur at several stations when comparing "observed" and "estimated" low flows. Of course part of the "error" may also be due to error in estimating the "observed" value). Large estimating errors for low flows were also evident in the literature and in previous investigations. It is not possible to accurately quantify the estimating error at individual stations since the absolute error calculation is exacerbated in many cases by the small observed low flow (eg. for several stations the $7Q_{20}$ value is close to zero and any non-zero simulated value could have very large absolute error). Therefore, for the purposes of this investigation, in order to compare the relative absolute errors of the different estimating techniques, the absolute value of the difference between the observed and simulated low flows

TABLE 5.3
COMPARISON OF ACTUAL AND ESTIMATED AVERAGE LOW FLOWS FOR TEST STATIONS**

		$7Q_2$ (m^3/s)	$7Q_{20}$ (m^3/s)	$7Q_2$ ($m^3/s/km^2$)	$7Q_{20}$ ($m^3/s/km^2$)	Method Rank
bserved Average (21 Stations)*		5.28	2.90	0.0022	0.0012	
ethod 1 Mapped Isolines		5.94	2.76	0.0025	0.0012	1
ethod 2 Graphical Index		6.25	2.67	0.0026	0.0011	2
ethod 3 Stat. Index	1)	5.94	2.45	0.0025	0.0010	3
	2)	6.26	3.33	0.0026	0.0014	
	3)	5.28	2.60	0.0022	0.0011	
	4)	5.28	2.50	0.0022	0.0010	
ethod 4 Regression		6.18	3.30	0.0026	0.0014	5
ethod 5 Proration		5.33	2.27	0.0022	0.0009	4

* Average DA = 2395 km^2 (Range 11.5 - 13400 km^2) (21 Stations)

** Based on Sub-Regions 1, 2, and 3.

TABLE 5.4
COMPARISON OF METHODS BY TESTING RESULTS

	Method 1		Method 2		Method 3		Method 4		Method 5	
	Mapped Isolines		Graphical Index Method		Statistical Index Method		Regression Method		Proration Method	
	Error Measure*	** Rank	Error Measure*	** Rank	Error Measure*	** Rank	Error Measure*	** Rank	Error Measure*	** Rank
1. Comparison of sample mean $7Q_2$	(13, -5)	1	(18, -8)	2	(13, -16)	3	(17, 13)	5	(1, -22)	4
2. Comparison of sample mean unit low flow $7Q_2$ (.0022 $m^3/s/km^2$) $7Q_{20}$ (.0012 $m^3/s/km^2$)	(14 , 0)	1	(18, -8)	2	(14, -17)	3***	(18, 17)	5***	(0, -25)	4***
3. Comparison based on N.S.R.^{2}	(.97, .96)	1	(.92, .87)	3	(.97, .92)	2	(.79, .87)	4	(.92, .48)	5
4. Comparison of average absolute error in the low flow estimate relative to the average low flow estimate for the 21 stations.	(15, 22)	1	(24, 39)	3	(15, 28)	2	(43, 47)	5	(25, 48)	4
5. Comparison of average absolute error in the unit low flow estimate relative to the average unit low flow estimate for the 21 stations	(23, 34)	1	(54, 60)	4	(23, 39)	2	(136, 100)	5	(35, 45)	3
*** Indicated methods "about equal for $7Q_{20}$" * Error measure % for ($7Q_2$, $7Q_{20}$) ** Rank of Method 1 = Best 5 = Worst Overall Rank		1		3		2		5		4

at each station was determined and the average found for the 21 sites. The "average absolute error" was then calculated as a percentage of the average recorded low flow for the 21 sites. A similar calculation was also done for the corresponding unit low flows for the 21 stations.

A comparison of the test results using the various estimating procedures and error assessment procedures is given in Table 5.4.

Overall, the Isoline Method produced the best results followed by the Statistical Index Method and Graphical Index Method in that order. The station Proration Method out-performed the regression method, although this might be attributed to the fact that over half of the stations tested were located within watersheds with other gauging stations.

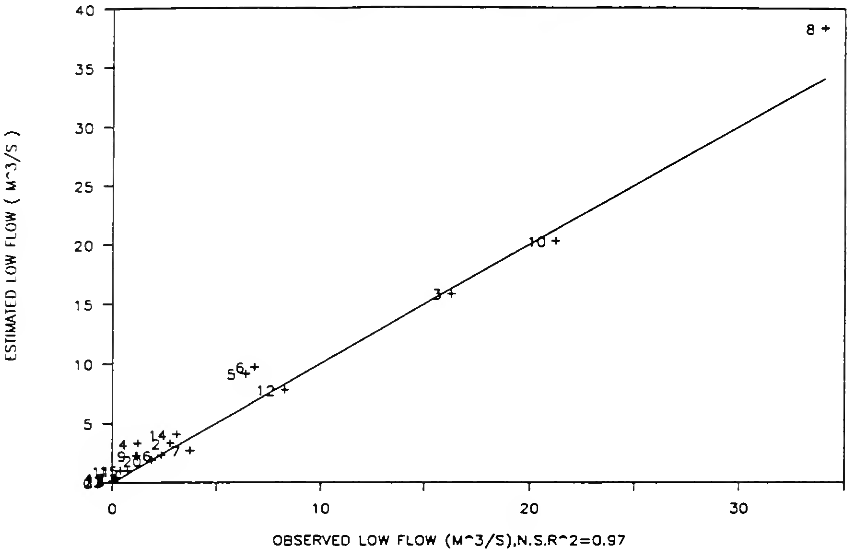
The application of the prediction methods at the test station has confirmed that, overall, the isoline method is the most robust technique for estimating low flows in the Northwestern and Northeastern Ontario.

It was also found that all the estimation techniques could not produce satisfactory results for some stations, based on the relatively high absolute error of estimate. It was found to be particularly difficult to estimate low flows for small watersheds in the north or areas where the $7Q_2$ or $7Q_{20}$ are observed to be very small or zero. In the latter case, only the use of methods where the index value can be calculated as zero (i.e. regression or use of local data) might provide acceptable results.

When utilizing a particular technique for predicting low flows at the test stations, it was found to be useful to compare the various prediction methods. This should also be undertaken when applying the procedures at ungauged watershed. For example, the mean of prediction methods (for each station) versus the observed low flows are given in Figure 5.6. The differences at some locations indicate that care should be taken when using these methodologies in estimating low flows for ungauged watersheds.

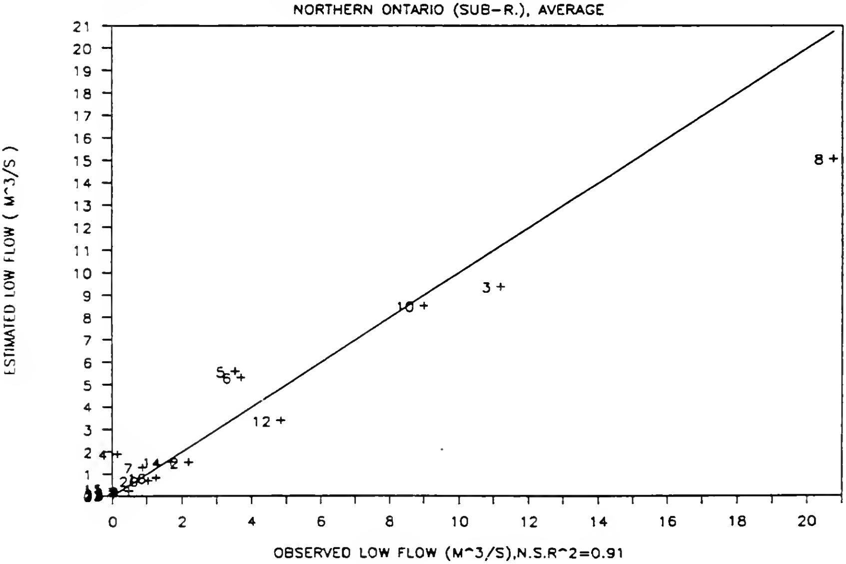
OBSERVED VERSUS ESTIMATED LOW FLOW 7Q2

NORTHERN ONTARIO (SUB-R.), AVERAGE



OBSERVED VERSUS ESTIMATED LOW FLOW 7Q20

NORTHERN ONTARIO (SUB-R.), AVERAGE



CCL	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	MEAN OF PREDICTION METHODS VS. OBSERVED LOW FLOWS FIGURE 5.6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1) No significant differences in $7Q_2$ and $7Q_{20}$ low flow statistics were found when the flow records were updated to the period of 1987 - 1990 when compared with the previously available data set.

2) The statistical indicators for trend were found to be very sensitive to changes in the available record length. However, it is possible that the apparent trend component, which has been identified using statistical tests, may not be an indicator of real trend in the data set due to the possibility of a cyclic nature in low flow statistics.

3) No significant changes in regional low flow statistics for $7Q_2$ and $7Q_{20}$ were found after trend adjustment techniques were applied to the original low flow time series.

4) The low flows appear to be homogeneous in the sense of probability frequency distribution. The Weibull III (W3) distribution was successfully fitted to almost all of the low flow time series available for Northern Ontario.

5) The low flows determined independently for winter and summer were found to belong to different populations for some of the stations in Northern Ontario.

6) The new application of a heterogeneity measure confirmed the identification of three statistical sub-regions in Northern Ontario.

7) The development of prediction techniques found that the most important parameter in the regionalization of low flow characteristics is the variation in watershed drainage area. Research should be undertaken to develop appropriate procedures to identify and incorporate other relevant factors such as seasonal and temporal variations in groundwater discharge, etc.

8) The isoline method was found to be the most robust estimating method, and provided the best prediction results on a regional basis, followed by the Statistical Index method and the Graphical Index Method.

9) The station proration method out performed the regression method, although this might be attributed to the fact that over half the test stations were located within watersheds with other gauging stations.

10) The accuracy of the prediction techniques for low flow ($7Q_2$ and $7Q_{20}$) is acceptable on a Regional Basis. However, large absolute errors at individual test stations were found to occur. Some of this "error" could be attributed to the higher information content provided by the regional estimating procedures. In any case, application of the techniques should be tempered by hydrologic experience and judgement and by comparison of methods.

11) Prediction of low flow characteristics for individual ungauged watersheds has proven to be significantly more difficult than for other hydrologic characteristics (eg. mean flow and peak flow conditions are relatively easier to predict).

12) The use of available at-site measurements (eg. short term data) can significantly improve low flow estimates (eg. by the statistical index method).

6.2 Recommendations

1) Additional research should be undertaken to examine possible trends in low flow time series. The sensitivity of trend indicators to the length of time period should be further investigated with additional long term data sets. This should include the investigation of possible relationships of low flow trend with climate change. Statistical and graphical techniques (such as RLWRS technique) should also be applied to assess the low flow data in the other regions of the Province of Ontario.

2) More detailed statistical tests should be applied to confirm the conclusions that the Annual/Winter/Summer low flows belong to different populations for some of the stations in Northern Ontario. This should include an assessment of the relative accuracy of low flow measurements during winter and summer.

3) The need for a seasonal low flow regionalization analysis should be investigated as a possible means of providing more accurate low flow predictions. (This would also be useful where seasonal - i.e. less conservative - estimates of low flows are required).

4) The development and application of non-dimensional statistical cluster analysis should be considered in similar future investigations for the purpose of refining the identification of homogeneous regions.

5) The low flow characteristics, (maps and isolines) for the remainder of Ontario should be updated to 1990 (or the most recent data base) using L-moments for fitting the data to the Weibull distribution. This should also include cluster and Statistical Homogeneity tests for the updated data base to provide consistency across the Province.

6) An overall operation manual should be developed for use in estimating low flow characteristics for all regions of Ontario using the findings from this and previous research investigations.

7) Up to date isoline maps should be refined with consistent areal and data base coverage across the entire Province.

8) An expanded data collection program for hydrometric data at a large number of locations in Northern Ontario should be undertaken. Strategies such as collection of short term data (eg. 5 - 10 years) should be considered to improve low flow estimates. Data collection platforms could then be moved from one location to another to maximize the use of resources over the long term.

9) Data analysis and management techniques are now available which would allow updating of low flow statistics on a frequent basis. We recommend that low flow characteristics should be updated every five (5) years in order to provide reasonably accurate information for investigations requiring low flow information.

REFERENCES

Armbruster, Jaffrey T., "Technical Manual For Estimating Low Flow Frequency Characteristics of Stream in the Susquehanna River Basin". PB-255455, U.S. Dept. of Commerce, National Tech. Information serve, U.S. Geological Survey, 1976

Berryman, David, Bernard Bobe, et al., "Nonparametric Tests for Trend Detection in Water Quality Time Series", Water Resources Bulletin, Vol. 24, No. 3, 1988

Bhaskar, Nageshwar R. and Carol A. O'Connor, "Comparison of Method of Residuals and Cluster Analysis for Flood Regionalization", Journal of Water Resources Planning and Management, Vol. 115, No. 6, 1989

Boals, R.G., "An Application of Time Series Analysis in Hydrometric Network Evaluation" Water Survey of Canada, Inland Water Directorate, Environment Canada, 1979

Bodo, Byron, Keith W. Hipel, A.I. McLeod, " Robust Trend Assessment of Water Quality Data Series" Environment Monitoring and Assessment, Vol 12, 1989

Burrel, Brian C., and James E. Anderson, "Regional Hydrology of New Brunswick", Canadian water Resources Journal, Vol. 16, No.4, 1991

Clarke, Robin T. and Luis Edgar, Montenego Terrazas, "The Use of L-Moments for Regionalizating Flow Records in the Rio Uruguai Basin: A Case Study", Regionalization in Hydrology, IAHS Publ. No. 191, 1990

Cumming Cockburn Limited, "Regional Analysis of Low Flow Characteristics for Southwestern and West Central Regions", Ministry of Environment, 1990

Cumming Cockburn Limited, "Regional Analysis of Low Flow Characteristics for Central and Southwestern Regions", Ministry of the Environment, 1991

El-Shaarawi, A.H. and Eivinal Damsleth, "Parametric and Nonparametric Tests for Dependent Data", Water Resources Bulletin, Vol. 24, No. 3, 1988

Gan K.C., T.A. McMahon, and I.C. O'Neill, "Errors in Estimated Streamflow Parameters and Storages for Ungauged Catchments", Water Resources Bulletin, Australia, 1990

Hardison, Clayton H., and Marshall E. Moss, "Accuracy of Low Flow Characteristics Estimated by Correlation of Base Flow Measurements", U.S. Department of the Interior, 1972

Hirsch, Robert M., "Statistical Methods and Sampling Design for Estimating Step Trends in Surface Water Quality", Water Resources Bulletin, Vol. 24, No. 3, 1988

Hirsch, Robert M., Richard B. Alexander and Richard A. Smith, "Selection of Methods for the Detection and Estimation of Trends in Water Quality", Water Resources Research, 1991

Hosking J.R.M., "L-moments: Analysis and Estimation of Distributions Using Linear Combinations of Order Statistics", J.R Statistics Vol. 51, No. 3, 1989

Hosking J.R.M. and J.R. Wallis, "Some Statistics Useful in Regional Frequency Analysis", Water Resources Research, Vol. 29, 1993

Khanna, V.K., "Regionalization of Low Flows in Central and Southern Alberta", Proceedings of The Canadian Hydrology Sumposium, No. 9, 1992 pp183 - 196

Leith, Rory M., Keith W. Hipel and Herman Goertz, "Exploratory Data Analysis", Canadian Water Resources Journal, 1991

Lettermaier, Dennis P., "Multivariate Nonparametric Tests for Trend in Water Quality", Water Resources Bulletin, Vol. 24, No. 3, 1988

Logan, L., "Working Group II - Receiving Water Assessment Techniques and Analysis", Water Management in Ontario Implementation

McLeod, A.I., "Trend Analysis Procedures for Water Quality Time Series", Dept. of Statistical and Actuarial Science, The University of Western Ontario, London, Ontario, 1990

McLeod, A. Ian, Keith W. Hipel, Fernando Comacho, "Trend Assessment of Water Quality Time Series", Water Resources Bulletin, 1983

McLeod, A.I., K.W. Hipel, "Trend Analysis Methodology for Water Quality Time Series", Environment Ontario, 1990

Melloh, Rae Ann, "Analysis of Winter Low Flow Rates in New Hampshire Streams", U.S. Army Corps of Engineers, 1990

Nathan, R.J. and T.A. McMahon, "Practical Aspects of Low Flow Frequency Analysis", Water Resources Research, Volume 26, No. 9, Australia 1990

Nie, N.H. et al, "Statistical Package for the Social Sciences (SPSS)", McGraw - Hill, 1975

Norusis, M.J., "Stacking Beers: Cluster Analysis", Advanced Statistics SPSS/PC+, SPSS Inc., 1986

Pilon, P.J., "The Weibull Distribution Applied to Regional Low Flow Frequency Analysis", Regionalization in Hydrology, IAHS Publ. No. 191, 1990

Rajaram, Harishar and Dennis McLaughlin, "Identification of Large-Scale Spatial Trends in Hydrologic Data", Water Resources Research, Vol. 26, No. 10, 1990

Riggs, H.C., "Techniques of Water Resources Investigations of the United States Geological Survey", U.S. Department of the Interior, 1972

Rochelle, Barry P., Donald L. Stevens Jr., and M. Robbins Church, "Uncertainty Analysis of Runoff Estimates From a Runoff Contour Map", Water Resources Bulletin, 1989

Rubach, Henning, "Application of Statistical Low Flow Analysis As a Basis for Water Quality Planning", International Symposium on Hydrometeorology, Germany, 1982

Stedinger, Jerry R. and Gray D. Tasker, "Regional Hydrologic Analysis, Ordinary, Weighted and Generalized Least Squares compared", Water Resources Research, Vol. 21, No. 9, 1985

Tasker, Gary D., "A comparison of Methods for Estimating Low Flow Characteristics of Streams", Water Resources Bulletin, Vol. 23, No. 6, 1988

Vogel, Richard M. and Charles N. Kroll, "Low Flow Frequency Analysis Using Probability - Plot Correlation Coefficients", Journal of Water Resources Planning and Management, Vol. 115, No. 3, 1989

Vogel, Richard M. and Charles N. Kroll, "Generalized Low Flow Frequency Relationships for Ungauged Sites in Massachusetts", Water Resources Bulletin Vol. 26, No. 2, 1990

Zelenhasic, Emir, and Atila Salvai, "A Method of Streamflow Drought Analysis", Water Resources Research, Vol. 23, No. 1, 1987

Zettergrist, Lena, "Statistical Estimation and Interpretation of Trends in Water Quality Time Series", Water Resources Research, Vol. 27, No. 7, 1991

APPENDIX A

TREND ANALYSIS METHODOLOGY

APPENDIX A
TREND ANALYSIS METHODOLOGY

A.1 Statistical Tests for Trend

i) Mann-Kendall Test

Mann (1945) and Kendall (1975) present a non-parametric test for trend. Letting X_1, X_2, ..., X_n be a sequence of low flow over time, Mann proposed to test the null hypothesis, H_o, that the data comes from a population where the random variables are independent and identically distributed. The alternative hypothesis, H_1, is the data follow a monotonic trend over time. Under H_o, the Mann-Kendall test statistic is:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn\ (x_i - x_k) \qquad \text{(A - 1)}$$

where sgn = 1 if x > 0

= 0 if x = 0

= -1 if x < 0

Kendall shows that S is asymptotically normally distributed and gave the mean and variance of S:

$$E\ (S) = 0 \qquad \text{(A - 2)}$$

$$Var\ (S) = n\ (n-1)\ (2n + 5)/18 \qquad \text{(A - 3)}$$

A positive value of S indicates there is an upward trend where the low flow increases with time. On the other hand, a negative value of S means that there is a downward trend. Because it is known that S is asymptotically normally distributed and has a mean of zero and variance given by equation A - 3, one can check whether or not an upward or downward trend is significantly different from zero. If the S is significantly different from zero, based upon the available information, H_0 can be rejected at a chosen significant level and the presence of a monotonic trend, H_1, can be accepted.

The exact distribution of S for n $\geq$10 was derived. Even for small values of n, the normality approximation is good provided one employs the standard normal variable Z given by:

$$
\begin{aligned}
Z_m &= (S-1)/(Var\ (S))^{1/2} && \text{if } S > 0 \\
&= 0 && \text{if } S = 0 \\
&= (S+1)/(Var\ (S))^{1/2} && \text{if } S < 0
\end{aligned}
\qquad (A - 4)
$$

A statistic which is closely related to S is Kendall's tau defined by:

$$\tau = S/D \qquad (A - 5)$$

where

$$D = n\,(n-1)/2 \qquad (A - 6)$$

Due to the relationship between τ and S, the distribution of τ can be easily obtained from the distribution of S.

The Mann-Kendall Test results for 7 day average low flows are given in Table A.1(a) for the Northwestern Region and Table A.1(b) for the Northeastern Region. Test results for the "old" data set (to 1986) and for the "new" data set (to 1990) are also summarized and compared in Table A.1.

ii) Spearman's Rho Test

Spearman (1904) introduced a non-parametric coefficient of rank correlation denoted as ρ_{xy} which is based upon the squared differences of ranks between two variables. By letting one of the variables represent time, Spearman's rho test can be interpreted as a trend test.

Let the sample consist of a bivariate sample (X_i, t_i) for i = 1, 2, ..., n, where n is the sample size. Suppose that the values of X variable are ranked from smallest to largest such that the rank of the smallest value is one and that of the largest value is n. Let $R_1^{(X)}$represent the rank of X variable measured at time t_i. Likewise, the values of Y variable can be ranked and $R_i^{(Y)}$ can represent the value of the rank for the Y variable. The sum of the squared differences of the rank is:

$$S\,(d^2) = D^2 = \sum_{i=1}^{n} (R_i^{(x)} - R_i^{(y)})^2 \tag{A - 7}$$

Spearman's rho is then defined as:

$$\rho_{xy} = 1 - \frac{6\,s\,(d^2)}{n^3 - n} \tag{A - 8}$$

When the two rankings of X and Y are identical $\rho_{xy} = 1$, whereas $\rho_{xy} = -1$ when the rankings of X and Y are in reverse order.

When using ρ_{xT} in a statistical test to check for a trend, the null hypothesis, H_o, is that there is no correlation, that is no trend on the time series. ρ_{xT} is distributed as $N\,(0, \frac{1}{n-1})$, where n is the sample size. The alternative hypothesis, H_1, is that there is correlation between X and T variables. If the estimated value of ρ_{xT} is significantly different from zero, then one can argue that time and X variable are significantly correlated, which in turn means there is a trend.

The Spearman Test results for trend are given in Table 3.1. A comparison of Spearman and Mann-Kendall test results (for selected stations) is given in Table A.2.

It was found that an additional four years of record could significantly affect trend statistics. Additional long term discharge measurements are required in order to undertake a complete statistical analysis of low flow trend.

A.2) Robust Locally Weighted Regression Smooth

In essence, robust locally weighted regression is a method for smoothing a scatter of (X_i, Y_i), $i = 1, 2, ..., n$, in which the fitted value at X_k is in the value of a polynomial fitted to the data using weighted least squares. The weight for (X_i, Y_i), is large if X_i is close to X_k and is small if this is not the case. To display graphically the RLWRS on the scatter plot of (X_i, Y_i), one plots $(X_i, \hat{Y}_i)$ on the same graph as the scatter plot of (X_i, Y_i), where $(X_i, \hat{Y}_i)$ is called the smoothed point at X_i and Y_i is called the fitted value at X_i.

General Procedure:

The general idea behind the smoothing procedure is as follows. Let W be a weight function which has the following properties:

1) $W(x) > 0$ for $|X| < 1$
2) $W(-X) = W(X)$
3) $W(X)$ is a non-increasing function for $X \geq 0$
4) $W(X) = 0$ for $|X| \geq 1$

If one lets $0<f<1$ and r be fn rounded to the nearest integer, the outline of the procedure is as given below. For each X_i, weight $W_k(X_i)$, are defined for all X_k, $k = 1, 2, \ldots, n$, by employing the weight function W. To accomplish this, centre W at X_i and scale W so that the point at which W first becomes zero is the rth nearest neighbour of X_i. To obtain the initial fitted value, Y_i, at each X_i, a dth degree polynomial is fitted to the data using weighted least squares with weights $W_k(X_i)$. This procedure is called locally weighted regression. Based upon the size of the residual $Y_i - \hat{Y}_i$, a different set of weights, δ_i, is defined for each (X_i, Y_i). In general, large residuals produce small weights while small residuals result in large weights. Because large residuals cause small weights, the effects of extremes tend to be toned down or smoothed, thereby making the procedure robust. After replacing $W_k(X_i)$ by $\delta_i W_k(X_i)$, new fitted values are computed using locally weighted regression. The determination of new weights and fitted values are repeated as often as required. All of the foregoing steps are referred to as robust locally weighted regression.

In the smoothing procedure, points in the neighbourhood of (X_i, Y_i) are used to calculate $\hat{Y}_i$. Because the weights $W_k(X_i)$ decrease as the distance of X_k from X_i increases, points whose abscissae are closer to X_i, have a larger effect upon the calculation of $\hat{Y}_i$ while further points play a lesser role. By increasing f, the neighbourhood of points affecting $\hat{Y}_i$ becomes larger. Therefore, larger values of f tend to cause smoother curves.

In the RLWRS procedure, local regression means that regression at a given point is carried out for a subset of nearest neighbours such that the observations closer to the specified point are given larger weights. By taking the size of the residuals into account for obtaining revised weights, robustness is brought into the procedure. Finally, the robust locally weighted regression analysis is carried out for each observation.

Specific Procedure:

1) Let the distance from X_i to the rth nearest neighbour of X_i be denoted by h_i for each i. Hence, h_i is the smallest number among $| X_i - X_j |$, for j = 1, 2, ..., n. For k = 1, 2, ..., n, let

$$W_k (X_i = W ((X_k - X_i)/h_i) \qquad \text{(A - 9)}$$

A possible form for the weight function is the tricube given by:

$$\begin{aligned} W(X) &= (1 - |X|^3)^3 \quad \text{for } |X| <1 \\ &= 0 \quad \text{for } |X| >1 \end{aligned} \qquad \text{(A - 10)}$$

2) The second step describes how locally weighted regression is carried out. For each i, determine the estimates $\beta_j (X_i)_1$ j = 1, ..., d, of the parameters in a polynomial regression of degree d of Y_k on X_k. This is fitted using weighted least squares having weight $W_k (X_i)$ for (X_k, Y_k). Therefore, the $\beta_j (X_i)$ are the values of β_i which minimize

$$\sum_{k=1}^{n} W_k (X_i) (y_k - \beta_0 \beta_i X_k - \beta_2 X_k^2 - \ldots - \beta_d X_k^d)^2 \qquad \text{(A - 11)}$$

When using locally weighted regression of degree d, the smoothed point at X_i is $(X_i, \hat{Y}_i)$ for which $\hat{Y}_i$ is the fitted value of the regression at X_i. Hence

$$\hat{y}_i = \sum_{j=0}^{d} \hat{\beta}_i (X_i) x_i^i = \sum_{k=1}^{n} r_k (X_i) Y_k \qquad \text{(A - 12)}$$

Where $\gamma_k (X_1)$ does not depend on Y_1, j = 1, 2, ..., n. The $\gamma_k (X_1$ are the coefficients for the Y_k coming from the regression.

3) Let the bisquare weight function be given by:

$$\begin{aligned} B(X) &= (1 - X^2)^2 \quad \text{for } |X| <1 \\ &= 0 \quad \text{for } |X| \geq 1 \end{aligned} \qquad \text{(A - 13)}$$

Let the residuals for the current fitted values be $e_i = Y_i - \hat{Y}_i$. The robustness weights are defined by:

$$\delta_K = \beta\ (e_k/6S) \qquad \text{(A - 14)}$$

where S is the median of the $| e_i |$

4) For each i, determine new $\hat{Y}_i$ by fitting a dth degree polynomial using weighted least squares having the weight $\delta_k\ W_k\ (X_k)$ at (X_k, Y_k).

5) Interactively execute steps 3 and 4 for a total t times. The final $\hat{Y}_i$ constitute the fitted values for the robust locally weighted regression and the $(X_i, \hat{Y}_i)$, i = 1, 2, ..., n, from the RLWRS. An increase in f causes an increase in the smoothness of the RLWRS. f = 0.5 often produces reasonable results. In practice, one can experiment with two or three value of f and select the one which produces the most informative smooth.

The parameter d is the order of the polynomial that is locally fitted to each point. d = 1, a linear polynomial usually results in a good smoothed curve that does not require high computational effort.

The parameter t stands for the number of iterations. t = 1 is sufficient for most applications.

The RLWRS analyses are summarized on Figure A.1 to A.46 for stations identified using the statistical tests as having "significant trend".

A.3 Trend Adjustment

In dealing with apparent trend in flow records, a technique was developed to adjust the time series. The procedure is as follows:

1. Fit a Robust Locally Weighted Regression Smooth, or just simply a linear regression smooth curve to the low flow time series.

2. Estimate the trend component in the data series for each station.

3. Obtain the rate of change per year (R_i, i = 1, ..., N) through the regression curve.

4. Adjust the recorded low flow Q_i by subtracting the total trend component in year i (R_i*i in linear regression, $\sum_{k=1}^{i} R_k$ in the case of RLWRS, i = 1, ..., N).

The graphical analyses summarized on Figures A.1 to A.46 summarize the RLWRS analysis. (The rate of change at there stations is given in Table 3.2). Subsequent to the adjustment for trend, the statistical tests were re-applied with the results summarized in Table A.3 it is evident that the trend was removed from the data at each station.

The low flow frequency analyses was then compared for the actual data set for these stations and for the "trend adjusted" data set. The results are summarized in table A.4. It was found that the trend adjustment did not result in any significant overall regional differences in low flow characteristics.

TABLE A.1(a)
TREND ANALYSIS FOR NEW DATA SET (1990)
NORTHWESTERN REGION
(Mann–Kendall)

Station Number	# of Years	Region Code	(1986) Data Set				(1990) Data Set			
			T	Z_m	5%	1%	T	Z_m	5%	1%
02AA001	68	3	0.15	1.732	No	No	0.086	1.032	No	No
02AB004	68	3	−0.148	−1.714	No	No	−0.221	−2.657	Yes	Yes
02AB006	64	3	−0.118	−1.287	No	No	−0.118	−1.373	No	No
02AB008	38	3	0.25	2.03	Yes	No	0.233	2.049	Yes	No
02AB009	34	3	0.197	1.48	No	No	0.091	0.741	No	No
02AB010	68	3	0.045	0.51	No	No	−0.018	−0.206	No	No
02AB011	67	3	0.085	0.97	No	No	0.023	0.271	No	No
02AB013	40	3	−0.313	−2.627	Yes	Yes	−0.422	−3.822	Yes	Yes
02AB014	19	3	0.152	0.743	No	No	0.053	0.28	No	No
02AB015	14	3	−0.165	−0.767	No	No	−0.154	−0.712	No	No
02AB016	14	3	0.154	0.712	No	No	0.198	0.932	No	No
02AB017	11	3	N/A	N/A	N/A	N/A	−0.145	−0.545	No	No
02AC001	20	3	0.13	0.676	No	No	0.189	1.136	No	No
02AD008	41	3	−0.33	−2.82	Yes	Yes	−0.326	−2.988	Yes	Yes
02AD009	48	3	0.045	0.425	No	No	0.045	0.444	No	No
02AD010	20	3	−0.105	−0.495	No	No	−0.121	−0.714	No	No
02AE001	17	3	0.455	1.992	Yes	No	0.338	1.854	No	No
02BA002	21	3	−0.059	−0.288	No	No	−0.138	−0.846	No	No
02BA003	19	3	0.165	0.766	No	No	−0.146	−0.84	No	No
02BB002	24	3	−0.135	−0.77	No	No	−0.348	−2.357	Yes	No
02BB003	21	3	0.033	0.135	No	No	0.019	0.091	No	No
04CA002	14	1	−0.19	−1.061	No	No	−0.337	−2.336	Yes	No
04CA003	24	1	0.292	−1.741	No	No	0.207	1.389	No	No
04CA004	19	1	−0.268	−1.515	No	No	−0.24	−1.399	No	No
04CB001	24	1	−0.368	−2.169	Yes	No	−0.428	−2.902	Yes	Yes
04CC001	19	1	0.103	0.428	No	No	−0.041	−0.21	No	No
04CD002	20	1	N/A	N/A	N/A	N/A	−0.253	−1.525	No	No
04CE002	23	1	0.039	0.189	No	No	−0.055	−0.343	No	No
04DA001	25	1	−0.295	−1.784	No	No	−0.413	−2.873	Yes	Yes
04DB001	25	1	0.247	1.492	No	No	−0.07	−0.467	No	No
04DC001	14	1	−0.279	−1.525	No	No	−0.383	−2.663	Yes	Yes
04DC002	24	1	0.013	0.038	No	No	−0.098	−0.645	No	No
04EA001	23	1	−0.02	−0.076	No	No	−0.257	−1.691	No	No
04FA001	25	1	−0.253	−1.53	No	No	−0.423	−2.943	Yes	Yes
04FA002	24	1	−0.263	−1.539	No	No	−0.275	−1.861	No	No
04FA003	25	1	−0.409	−2.414	Yes	No	−0.463	−3.223	Yes	Yes
04FB001	24	1	−0.058	−0.324	No	No	−0.357	−2.476	Yes	No
04FC001	23	1	−0.105	−0.595	No	No	−0.273	−1.796	No	No
04GA002	23	3	−0.15	−0.766	No	No	−0.119	−0.725	No	No
04GB001	50	3	−0.026	−0.245	No	No	−0.064	−0.652	No	No
04GB004	20	3	0.124	0.594	No	No	−0.105	−0.616	No	No
04GC002	16	1	−0.143	−0.693	No	No	−0.25	−1.306	No	No

TABLE A.1(a)
TREND ANALYSIS FOR NEW DATA SET (1990)
NORTHWESTERN REGION
(Mann–Kendall)

Station Number	# of Years	Region Code	(1986) Data Set				(1990) Data Set			
			T	Z_m	5%	1%	T	Z_m	5%	1%
04GD001	22	1	−0.311	−1.882	No	No	−0.47	−3.27	Yes	Yes
04JA002	37	1	−0.019	−0.15	No	No	−0.06	−0.51	No	No
04JC002	41	1	0.162	1.376	No	No	0.102	0.932	No	No
04JC003	37	1	−0.09	−0.763	No	No	−0.129	−1.112	No	No
04JD002	51	1	−0.224	−2.24	Yes	No	−0.213	−2.193	Yes	No
04JD003	52	1	−0.134	−1.333	No	No	−0.155	−1.618	No	No
04JF001	22	1	−0.235	−1.277	No	No	−0.446	−2.877	Yes	Yes
04JG001	24	1	N/A	N/A	N/A	N/A	−0.167	−1.116	No	No
05PA006	70	2	0.213	2.485	Yes	No	0.242	2.961	Yes	Yes
05PA012	64	2	0.095	1.053	No	No	0.117	1.362	No	No
05PB009	28	2	−0.269	−1.77	No	No	−0.373	−2.766	Yes	Yes
05PB014	72	2	0.233	2.693	Yes	No	0.254	3.155	Yes	Yes
05PB018	12	2	N/A	N/A	N/A	N/A	−0.288	−1.236	No	No
05PC018	11	2	0.147	1.623	No	No	0.047	0.534	No	No
05PC019	30	2	0.032	0.416	No	No	−0.051	−0.697	No	No
05PD015	20	2	−0.343	−1.733	No	No	−0.279	−1.687	No	No
05PD017	20	2	0	0	No	No	0	0	No	No
05PD023	19	2	−0.343	1.733	No	No	−0.094	−0.525	No	No
05PD026	12	2	N/A	N/A	N/A	N/A	−0.652	−2.885	Yes	Yes
05PE005	23	2	0.229	1.288	No	No	0.241	1.585	No	No
05PE006	33	2	0.437	5.69	Yes	Yes	0.411	5.528	Yes	Yes
05PE011	33	2	0.161	2.014	Yes	No	0.095	1.221	No	No
05QA001	60	2	0.06	0.676	No	No	0.026	0.286	No	No
05QA002	70	2	0.123	1.44	No	No	0.123	1.496	No	No
05QA004	30	2	−0.087	−0.584	No	No	−0.274	−2.105	Yes	No
05QB006	34	2	0.046	0.339	No	No	0.041	0.326	No	No
05QC001	29	2	−0.076	−0.496	No	No	−0.246	−1.857	No	No
05QC003	21	2	−0.324	−1.772	No	No	−0.448	−2.809	Yes	Yes
05QD003	27	2	−0.187	−1.085	No	No	−0.145	−1.042	No	No
05QD006	28	2	−0.068	−0.542	No	No	−0.175	−1.534	No	No
05QD016	21	2	N/A	N/A	N/A	N/A	−0.186	−1.148	No	No
05QE006	49	2	−0.091	−1.181	No	No	−0.064	−0.638	No	No
05QE007	35	2	−0.154	−1.178	No	No	−0.183	−1.534	No	No
05QE008	21	2	−0.5	−2.761	Yes	No	−0.581	−3.655	Yes	Yes
05QE009	31	2	−0.094	−0.62	No	No	−0.249	−1.955	No	No
05QE012	11	2	N/A	N/A	N/A	N/A	−0.236	−0.934	No	No
05RC001	11	2	N/A	N/A	N/A	N/A	−0.164	−0.623	No	No

Yes– There is a Trend
No– No Trend

TABLE A.1(b)
TREND ANALYSIS FOR NEW DATA SET (1990)
NORTHEASTERN REGION
(Mann–Kendall)

Station Number	# of Years	Region Code	(1986) Data Set				(1990) Data Set			
			T	Z_m	5%	1%	T	Z_m	5%	1%
02BD002	71	3	0.389	4.34	Yes	Yes	0.421	5.192	Yes	Yes
02BE002	56	3	0.398	4.11	Yes	Yes	0.266	2.891	Yes	Yes
02BF001	24	3	0.076	0.42	No	No	−0.178	−1.191	No	No
02BF002	24	3	−0.018	−0.07	No	No	−0.199	−1.34	No	No
02BF004	12	3	N/A	N/A	N/A	N/A	−0.5	−2.198	Yes	No
02BF005	11	3	N/A	N/A	N/A	N/A	−0.2	−0.778	No	No
02BF006	12	3	N/A	N/A	N/A	N/A	−0.455	−1.992	Yes	No
02BF007	10	3	N/A	N/A	N/A	N/A	−0.067	−0.179	No	No
02BF008	11	3	N/A	N/A	N/A	N/A	−0.236	−0.934	No	No
02BF009	10	3	N/A	N/A	N/A	N/A	0	0	No	No
02CA001	118	3	N/A	N/A	N/A	N/A	0.003	0.049	No	No
02CA002	20	3	0.067	0.297	No	No	−0.163	−0.973	No	No
02CB001	40	3	N/A	N/A	N/A	N/A	−0.29	−2.622	Yes	Yes
02CB003	11	3	N/A	N/A	N/A	N/A	−0.345	−1.401	No	No
02CC007	41	3	N/A	N/A	N/A	N/A	−0.051	−0.461	No	No
02CC008	41	3	0.448	3.584	Yes	Yes	0.024	0.21	No	No
02CC009	31	3	N/A	N/A	N/A	N/A	−0.123	−0.952	No	No
02CC010	11	3	N/A	N/A	N/A	N/A	−0.127	−0.467	No	No
02CD001	25	3	0.011	0.032	No	No	−0.193	−1.331	No	No
02CD002	14	3	N/A	N/A	N/A	N/A	−0.253	−1.206	No	No
02CD003	14	3	N/A	N/A	N/A	N/A	−0.275	−1.315	No	No
02CD004	22	3	N/A	N/A	N/A	N/A	−0.165	−1.044	No	No
02CD006	23	3	0.055	0.156	No	No	−0.166	−1.083	No	No
02CE001	44	3	−0.189	−1.635	No	No	−0.254	−2.417	Yes	No
02CE002	76	3	−0.012	−0.013	No	No	−0.019	−0.242	No	No
02CE004	71	3	−0.195	−2.308	Yes	No	−0.216	−2.656	Yes	Yes
02CF005	32	3	−0.422	−3.064	Yes	Yes	−0.462	−3.698	Yes	Yes
02CF007	31	3	0.323	2.293	Yes	No	0.144	1.122	No	No
02CF008	31	3	0.121	0.481	No	No	−0.402	−3.105	Yes	Yes
02CF009	32	3	−0.24	−1.66	No	No	−0.369	−2.592	Yes	Yes
02CF010	15	3	0.273	1.09	No	No	0.029	0.009	No	No
02CF011	20	3	−0.303	−1.305	No	No	−0.384	−2.336	Yes	No
02CF012	14	3	N/A	N/A	N/A	N/A	−0.011	0	No	No
02CF013	10	3	N/A	N/A	N/A	N/A	0.022	0	No	No
02DB005	39	3	−0.314	−2.594	Yes	Yes	−0.424	−3.787	Yes	Yes
02DB007	11	3	N/A	N/A	N/A	N/A	−0.091	−0.311	No	No
02DC003	70	3	0.058	0.674	No	No	−0.042	−0.512	No	No
02DC007	53	3	0.119	1.182	No	No	0.239	2.516	Yes	No
02DC008	53	3	0.166	1.653	No	No	0.115	1.204	No	No
02DD005	47	3	−0.154	−1.552	No	No	−0.153	−1.504	No	No
02DD008	27	3	0.218	1.543	No	No	0.179	1.293	No	No
02DD009	35	3	−0.133	−0.994	No	No	−0.25	−2.102	Yes	No

TABLE A.1(b)
TRENDS ANALYSIS FOR NEW DATA SET (1990)
NORTHEASTERN REGION
(Mann–Kendall)

Station Number	# of Years	Region Code	(1986) Data Set				(1990) Data Set			
			T	Z_m	5%	1%	T	Z_m	5%	1%
02DD010	30	3	0.33	2.289	Yes	No	0.179	1.374	No	No
02DD013	17	3	0.409	1.786	No	No	−0.272	−1.483	No	No
02DD015	17	3	0.333	1.442	No	No	−0.147	−0.783	No	No
02DD016	11	3	N/A	N/A	N/A	N/A	−0.527	−2.18	Yes	No
02DD017	11	3	N/A	N/A	N/A	N/A	−0.127	−0.467	No	No
02EA005	76	3	0.159	1.956	No	No	0.064	0.812	No	No
02EA006	76	3	−0.136	−1.678	No	No	−0.229	−2.929	Yes	Yes
02EA010	23	3	0.018	0.07	No	No	−0.292	−1.928	No	No
02EA011	18	3	0.179	0.794	No	No	−0.229	−1.288	No	No
02EA013	12	3	0.473	1.946	No	No	0.473	1.946	No	No
02EA014	10	3	N/A	N/A	N/A	N/A	−0.556	−2.147	Yes	No
02JC008	23	3	0.078	0.417	No	No	0.237	1.559	No	No
02JD010	19	3	N/A	N/A	N/A	N/A	−0.228	−1.329	No	No
02JD011	45	3	N/A	N/A	N/A	N/A	−0.098	−0.939	No	No
02JE012	39	3	N/A	N/A	N/A	N/A	−0.178	−1.585	No	No
02JE018	12	3	−0.255	−1.012	No	No	−0.288	−1.236	No	No
02JE019	19	3	0.086	0.396	No	No	0.047	0.245	No	No
02JE020	20	3	−0.01	0	No	No	−0.168	−1.006	No	No
02JE021	45	3	N/A	N/A	N/A	N/A	−0.081	−0.773	No	No
04KA001	21	3	0.017	0.045	No	No	−0.243	−1.51	No	No
04LA002	22	1	N/A	N/A	N/A	N/A	−0.177	−1.128	No	No
04LD001	70	1	0.217	2.503	Yes	No	0.221	2.697	Yes	Yes
04LF001	73	1	−0.077	−0.926	No	No	−0.066	−0.824	No	No
04LG002	24	1	−0.36	−2.377	Yes	No	−0.37	−2.506	Yes	No
04LJ001	71	1	0.004	0.039	No	No	0.009	0.104	No	No
04LM001	19	1	0.077	0.305	No	No	0.018	0.07	No	No
04MB003	37	1	N/A	N/A	N/A	N/A	−0.054	−0.458	No	No
04MC001	71	1	N/A	N/A	N/A	N/A	0.452	5.574	Yes	Yes
04MD002	53	1	−0.213	−2.124	Yes	No	−0.239	−2.516	Yes	No
04MD004	14	1	0.778	3.041	Yes	Yes	0.626	3.069	Yes	Yes
04ME002	59	1	0.029	−0.298	No	No	0.019	0.203	No	No
04ME003	32	1	N/A	N/A	N/A	N/A	−0.01	−0.065	No	No
04ME004	30	1	−0.387	−2.686	Yes	Yes	−0.269	−2.07	Yes	No
04MF001	25	1	−0.374	−2.271	Yes	No	−0.277	−1.915	No	No

Yes – There is a Trend
No – No Trend

SUMMARY OF STATIONS WITH SIGNIFICANT TREND
NORTHWESTERN REGION
(-1986)

Station No.	Trend (7 Day Low Flow)													
	Spearman Test							Mann-Kendall Test						
	S.C.	D.F.	S.T.	5%		1%		t	S.D.	Z_m	5%		1%	
				T.L.	T.I.	T.L.	T.I.				T.L.	T.I.	T.L.	T.I.
02AB008	-0.351	31	-2.088	-2.04	Yes	-2.745	No	0.25	64.5	2.03	1.96	Yes	2.57	No
02AB013	0.431	33	2.743	2.036	Yes	2.736	Yes	-0.313	70.4	-2.627	1.96	Yes	2.57	Yes
02AD008	0.505	34	3.407	2.034	Yes	2.732	Yes	-0.33	73.4	-2.82	1.96	Yes	2.57	Yes
02AE001	-0.608	10	-2.424	-2.228	Yes	-3.169	No	0.455	14.6	1.992	1.96	Yes	2.57	No
04CB001	0.521	17	2.517	2.11	Yes	2.898	No	-0.368	28.6	-2.169	1.96	Yes	2.57	No
04FA002	0.537	17	2.624	2.11	Yes	2.898	No	-0.263	28.6	-1.539	1.96	No	2.57	No
04FA003	0.532	17	2.589	2.11	Yes	2.898	No	-0.409	28.6	-2.414	1.96	Yes	2.57	No
04GA001	0.874	49	12.619	2.012	Yes	2.684	Yes	-0.625	123.1	-6.465	1.96	Yes	2.57	Yes
04JD002	0.573	46	4.742	2.015	Yes	2.691	Yes	-0.224	112.5	-2.24	1.96	Yes	2.57	No
05PA006	-0.331	62	-2.762	-1.998	Yes	-2.659	Yes	0.213	172.6	2.485	1.96	Yes	2.57	No
05PB009	0.416	21	2.094	2.080	Yes	2.831	No	-0.269	37.9	-1.77	1.96	No	2.57	No
05PB014	-0.365	61	-3.061	-2.0	Yes	-2.659	Yes	0.233	168.6	2.693	1.96	Yes	2.57	Yes
05PD023	0.546	13	2.351	2.16	Yes	3.012	No	-0.343	20.2	-1.733	1.96	No	2.57	No
05PE006	-0.611	77	-6.778	-1.994	Yes	-2.648	Yes	0.437	236.2	5.69	1.96	Yes	2.57	Yes
05PE011	-0.239	71	-2.071	-1.996	Yes	-2.652	No	0.161	209.9	2.014	1.96	Yes	2.57	No
05QE008	0.652	15	3.33	2.131	Yes	2.947	Yes	-0.5	29.3	-2.761	1.96	Yes	2.57	Yes

LEGEND:

S.C. : Spearman Coefficient
D.F. : Degrees of Freedom
S.T. : Studentized Coefficient
T.L. : Test Limit
T.I. : Trend Indicator
t : Tau
S.D. : Standard Deviation
Z : Mann-Kendall Variable

TABLE A.2(b)
SUMMARY OF STATIONS WITH SIGNIFICANT TREND
NORTHEASTERN REGION
(-1986)

Station No.	Trend (7 Day Low Flow)													
	Spearman Test							Mann-Kendall Test						
	S.C.	D.F.	S.T.	5%		1%		t	S.D.	Z_m	5%		1%	
				T.L.	T.I.	T.L.	T.I.				T.L.	T.I.	T.L.	T.I.
02BD002	-0.528	57	-4.693	-2.003	Yes	-2.667	Yes	0.389	152.9	4.34	1.96	Yes	2.57	Yes
02BE002	-0.495	49	-3.983	-2.012	Yes	-2.684	Yes	0.398	123.1	4.11	1.96	Yes	2.57	Yes
02CC008	-0.607	30	-4.406	-2.042	Yes	-2.750	Yes	0.448	61.7	3.584	1.96	Yes	2.57	Yes
02CE004	0.31	64	2.610	1.999	Yes	2.657	No	-0.195	180.7	-2.308	1.96	Yes	2.57	No
02CF004	0.363	66	3.168	1.998	Yes	2.656	Yes	-0.25	188.9	-3.007	1.96	Yes	2.57	Yes
02CF005	0.607	25	3.824	2.060	Yes	2.787	Yes	-0.422	49.9	-3.064	1.96	Yes	2.57	Yes
02CF007	0.478	24	-2.663	-2.064	Yes	-2.797	No	0.323	45.4	2.293	1.96	Yes	2.57	No
02DB005	0.474	32	3.043	2.038	Yes	2.741	Yes	-0.314	67.5	-2.594	1.96	Yes	2.57	Yes
02DC007	-0.419	46	-3.128	-2.015	Yes	-2.691	Yes	0.119	112.5	1.182	1.96	No	2.57	No
02DC008	-0.29	46	-2.057	-2.015	Yes	-2.691	No	-0.166	112.5	1.653	1.96	No	2.57	No
02DD010	-0.43	23	-2.285	-2.069	Yes	-2.807	No	0.33	43.8	2.289	1.96	Yes	2.57	No
02EA013	-0.696	9	-2.908	-2.262	Yes	-3.25	No	0.473	12.8	1.946	1.96	No	2.57	No
02JD012	-0.688	39	-5.915	-2.023	Yes	-2.709	Yes	0.449	89.0	4.122	1.96	Yes	2.57	Yes
04LD001	-0.318	61	-2.623	-2.0	Yes	-2.659	No	0.217	168.6	2.503	1.96	Yes	2.57	No
04LG002	0.512	21	2.730	2.08	Yes	2.831	No	-0.360	37.9	-2.377	1.96	Yes	2.57	No
04MD002	0.429	46	3.224	2.015	Yes	2.691	Yes	-0.213	112.5	-2.124	1.96	Yes	2.57	No
04MD004	-0.927	8	-7.005	-2.306	Yes	-3.355	Yes	0.778	11.2	3.041	1.96	Yes	2.57	Yes
04ME004	0.492	23	2.713	2.069	Yes	2.807	No	-0.387	42.8	-2.686	1.96	Yes	2.57	Yes
04MF001	0.536	18	2.69	2.101	Yes	2.878	No	-0.374	30.8	-2.271	1.96	Yes	2.57	No

LEGEND:

S.C. : Spearman Coefficient
D.F. : Degrees of Freedom
S.T. : Studentized Coefficient
T.L. : Test Limit
T.I. : Trend Indicator
t : Tau
S.D. : Standard Deviation
Z : Mann-Kendall Variable

TABLE A.3(a)
TREND DETECTION BEFORE AND AFTER TREND ADJUSTMENT
NORTHWESTERN REGION

Station Number	# of Years	Region Code	Before Adjustment				After Adjustment			
			T	Z_m	5%	1%	T	Z_m	5%	1%
02AB004	68	3	−0.221	−2.657	Yes	Yes	0.007	0.085	No	No
02AB013	40	3	−0.422	−3.822	Yes	Yes	0.062	0.548	No	No
02AD008	41	3	−0.326	−2.988	Yes	Yes	−0.107	−0.977	No	No
02BB002	24	3	−0.348	−2.357	Yes	No	−0.152	−1.017	No	No
04CA002	14	1	−0.337	−2.336	Yes	No	−0.1	−0.677	No	No
04CB001	24	1	−0.428	−2.902	Yes	Yes	−0.275	−1.861	No	No
04DA001	25	1	−0.413	−2.873	Yes	Yes	−0.173	−1.191	No	No
04DC001	14	1	−0.383	−2.663	Yes	Yes	−0.033	−0.21	No	No
04FA001	25	1	−0.423	−2.943	Yes	Yes	−0.167	−1.144	No	No
04FA003	25	1	−0.463	−3.223	Yes	Yes	−0.247	−1.705	No	No
04FB001	24	1	−0.357	−2.476	Yes	No	0.143	0.981	No	No
04GD001	22	4	−0.47	−3.27	Yes	Yes	−0.043	−0.28	No	No
04JD002	51	4	−0.213	−2.193	Yes	No	0.082	0.845	No	No
04JF001	22	4	−0.446	−2.877	Yes	Yes	0.281	1.805	No	No
05PA006	70	2	0.242	2.961	Yes	Yes	0.122	1.485	No	No
05PB009	28	2	−0.373	−2.766	Yes	Yes	−0.153	−1.126	No	No
05PB014	72	2	0.254	3.155	Yes	Yes	0.009	0.112	No	No
05PD026	12	2	−0.652	−2.885	Yes	Yes	−0.409	−1.786	No	No
05PE006	33	2	0.411	−5.528	Yes	Yes	0.133	1.785	No	No
05QA004	30	2	−0.274	−2.105	Yes	No	−0.11	−0.839	No	No
05QC003	21	2	−0.448	−2.809	Yes	Yes	−0.214	−1.329	No	No
05QE008	21	2	−0.581	−3.655	Yes	Yes	−0.219	−1.359	No	No

Yes – There is a Trend
No – No Trend

TABLE A.3(b)
TREND DETECTION BEFORE AND AFTER TREND ADJUSTMENT
NORTHEASTERN REGION

Station Number	# of Years	Region Code	Before Adjustment T	Before Adjustment Z_m	Before Adjustment 5%	Before Adjustment 1%	After Adjustment T	After Adjustment Z_m	After Adjustment 5%	After Adjustment 1%
02BD002	70	3	0.421	5.192	Yes	Yes	0.096	1.181	No	No
02BE002	56	3	0.266	2.891	Yes	Yes	0.134	1.456	No	No
02BF004	12	3	−0.5	−2.198	Yes	No	−0.167	−0.687	No	No
02BF006	12	3	−0.455	−1.992	Yes	No	0	0	No	No
02CB001	40	3	−0.29	−2.622	Yes	Yes	−0.106	−0.955	No	No
02CE001	44	3	−0.254	−2.417	Yes	No	−0.199	−1.891	No	No
02CE004	71	3	−0.216	−2.656	Yes	Yes	−0.124	−1.519	No	No
02CF005	32	3	−0.462	−3.698	Yes	Yes	−0.161	−1.281	No	No
02CF008	30	3	−0.402	−3.105	Yes	Yes	0.021	0.143	No	No
02CF009	32	3	−0.369	−2.952	Yes	Yes	0	0	No	No
02CF011	20	3	−0.384	−2.336	Yes	No	−0.226	−1.363	No	No
02DB005	39	3	−0.424	−3.787	Yes	Yes	−0.188	−1.669	No	No
02DC007	53	3	0.239	2.516	Yes	No	−0.073	−0.767	No	No
02DD009	35	3	−0.25	−2.102	Yes	No	−0.113	−0.937	No	No
02DD016	11	3	−0.527	−2.18	Yes	No	0.018	0	No	No
02EA006	76	3	−0.229	−2.929	Yes	Yes	−0.093	−1.188	No	No
02EB014	10	3	−0.556	−2.147	Yes	No	−0.089	−0.268	No	No
04LD001	70	4	0.221	2.697	Yes	Yes	0.09	1.1	No	No
04LG002	24	4	−0.37	−2.506	Yes	No	−0.188	−1.265	No	No
04MC001	36	4	0.452	5.574	Yes	Yes	0.12	1.479	No	No
04MD002	53	4	−0.239	−2.516	Yes	No	0.076	0.798	No	No
04MD004	14	4	0.626	3.069	Yes	Yes	0.352	1.699	No	No
04ME004	30	4	−0.269	−2.07	Yes	No	−0.126	−0.964	No	No

Yes− There is a Trend
No− No Trend

TABLE A.4(a)

COMPARISON OF FREQUENCY ANALYSIS BEFORE AND AFTER TREND ADJUSTMENT

NORTHWESTERN REGION

Station Number	# of Years	Region Code	BEFORE ADJUSTMENT $7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda1	lambda2	L-CV	L-CS	L-CK
02AB004	68	3	0.48	0.05	0.012	0.003	1.81	1.48	0.82	0.69	0.41
02AB013	40	3	0.059	0.01	0.001	0	0.23	0.16	0.72	0.6	0.44
02AD008	41	3	226.5	168.4	136.3	109.6	222.5	37.2	0.17	0.12	0.148
02BB002	24	3	3.928	2.49	1.77	1.21	3.97	0.84	0.211	0.005	0.357
04CA002	14	1	78.52	62.73	52.58	43.07	75.9	9.84	0.13	-0.18	0.26
04CB001	24	1	42.93	34.06	30.06	27.2	43.58	6.54	0.15	-0.01	0.03
04DA001	25	1	8.98	6.72	6.02	5.64	9.88	1.97	0.2	0.32	0.28
04DC001	14	1	85.77	74.17	66.9	60.22	84.05	7.49	0.09	-0.18	0.09
04FA001	25	1	16.05	12.14	10.67	9.75	16.91	2.78	0.16	0.26	0.31
04FA003	25	1	6.38	4.74	4.03	3.54	6.55	1.18	0.18	0.12	0.13
04FB001	24	1	48.93	38.32	32.23	26.99	48.11	6.41	0.13	-0.14	0.3
04GD001	22	4	56.57	43.22	36.07	30.23	55.98	8.42	0.15	-0.11	0.25
04JD002	51	4	0.001	0	0	0	0.06	0.05	0.93	0.86	0.68
04JF001	22	4	12.18	8.59	7.44	6.8	13.53	2.71	0.2	0.24	0.45
05PA006	70	2	34.05	24.59	20.74	18.18	35.54	6.85	0.19	0.1	0.16
05PB009	28	2	10.39	3.73	1.62	0.47	12.94	6.26	0.48	0.14	-0.02
05PB014	72	2	11.73	7.91	6.08	4.71	11.86	2.53	0.213	0.06	0.13
05PD026	12	2	0.4	0.14	0.05	0	0.46	0.21	0.46	0.02	-0.13
05PE006	33	2	52.54	27.99	17.36	10.01	55.17	17.34	0.31	-0.07	-0.08
05QA004	30	2	13.59	10.14	8.25	6.7	13.4	2.2	0.16	-0.06	0.21
05QC003	21	2	7.74	4.8	3.47	2.52	7.93	2.17	0.27	-0.01	0.02
05QE008	21	2	3.71	2.43	2.08	1.9	4.39	1.18	0.27	0.1	0
Average			32.79	24.43	20.17	16.76					
Averag/km^2			0.0020	0.0014	0.0011	0.0009					

Station Number	AFTER ADJUSTMENT $7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda1	lambda2	L-CV	L-CS	L-CK
02AB004	0.516	0.061	0.014	0.003	1.84	1.452	0.789	0.685	0.427
02AB013	0.078	0.011	0.003	0.001	0.238	0.142	0.597	0.559	0.504
02AD008	222.4	173.2	149.6	132	224.1	33.05	0.147	-0.011	0.167
02BB002	3.958	2.744	2.147	1.692	3.998	0.737	0.184	0.06	0.274
04CA002	78.46	66.85	54.23	46.02	104.1	20.44	0.196	0.155	0.328
04CB001	44	36.19	32.19	29.06	43.83	5.44	0.124	-0.036	0.042
04DA001	9.6	6.88	5.76	5.01	10.02	1.723	0.172	0.269	0.343
04DC001	88.44	69.07	65.15	63.61	107.32	18.28	0.17	0.48	0.594
04FA001	16.54	12.77	11.21	10.17	17.12	2.39	0.14	0.239	0.319
04FA003	6.368	5.11	4.632	4.333	6.64	1.001	0.151	0.111	0.061
04FB001	47	34.97	31.86	30.4	54.35	10.18	0.187	0.37	0.45
04GD001	60.78	45.01	39.22	35.7	64.69	12.07	0.187	0.217	0.282
04JD002	0.015	0.0014	0.0003	0.0001	0.065	0.053	0.809	0.705	0.502
04JF001	12.75	9.554	8.481	7.868	13.789	2.517	0.183	0.251	0.334
05PA006	34.53	25.08	20.95	18.06	35.49	6.472	0.182	0.114	0.165
05PB009	11.01	4.558	2.389	1.149	13.158	5.444	0.414	0.105	-0.013
05PB014	11.6	8.123	6.533	5.387	11.839	2.367	0.2	0.101	0.118
05PD026	0.407	0.275	0.238	0.22	0.478	0.143	0.299	0.27	-0.032
05PE006	60.56	36.85	25.52	17.06	61.25	16.26	0.266	0.025	0.024
05QA004	13.64	10.38	8.58	7.07	13.449	2.045	0.152	-0.041	0.188
05QC003	8.342	5.731	4.294	3.098	8.144	1.787	0.219	-0.076	0.059
05QE008	4.739	3.507	2.765	2.105	4.584	0.796	0.174	-0.118	0.176
Average	33.44	25.31	27.76	19.09					
Averag/km^2	0.0021	0.0015	0.0013	0.0011					

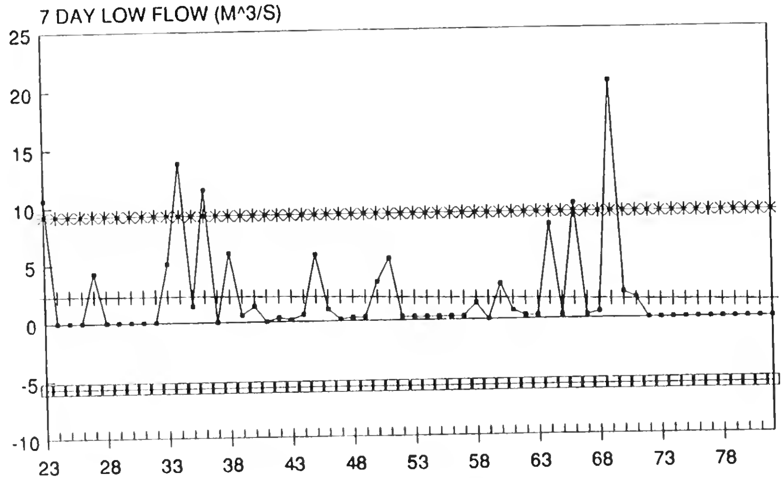
TABLE A.4(b)

COMPARISON OF FREQUENCY ANALYSIS BEFORE AND AFTER TREND ADJUSTMENT

NORTHEASTERN REGION

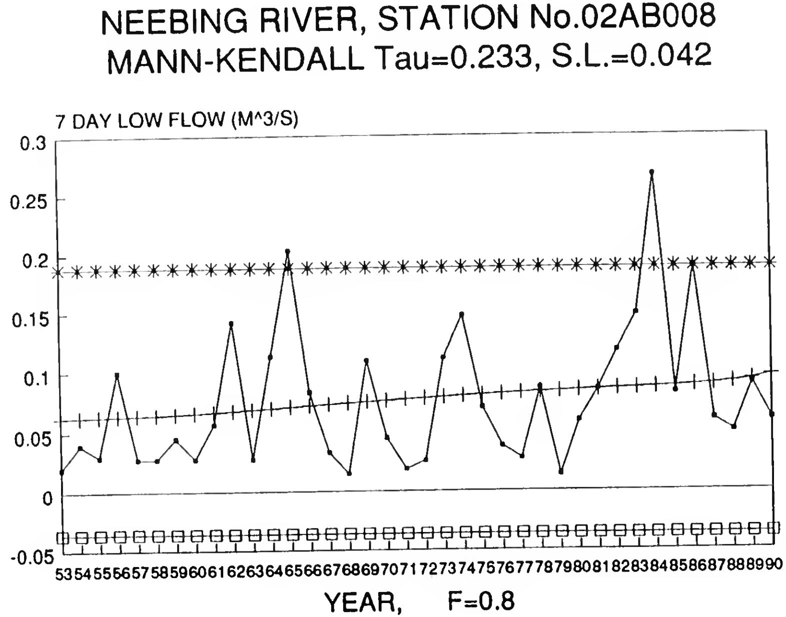
Station	# of	Region	BEFORE ADJUSTMENT									AFTER ADJUSTMENT								
Number	Years	Code	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda1	lambda2	L–CV	L–CS	L–CK	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda1	lambda2	L–CV	L–CS	L–CK
02BD002	70	3	29.33	19.29	14.86	11.76	30.25	6.99	0.23	0.13	1.11	30.07	20.46	15.33	11.18	29.81	5.758	0.193	0.004	0.243
02BE002	56	3	16.77	10.55	7.39	4.91	16.7	4.14	0.25	0	0.11	16.86	10.94	7.837	5.356	16.649	3.92	0.235	−0.028	0.096
02BF004	12	3	0.04	0.23	0.02	0.02	0.07	0.03	0.44	0.58	0.51	0.049	0.033	0.03	0.029	0.073	0.028	0.383	0.646	0.524
02BF006	12	3	0.01	0.002	0	0	0.02	0.01	0.7	0.46	0.16	0.014	0.003	0.0005	0	0.021	0.011	0.549	0.423	0.311
02CB001	40	3	6.36	2.64	1.46	0.81	7.77	3.4	0.44	0.19	0.05	6.298	2.863	1.832	1.29	7.827	3.115	0.398	0.208	0.094
02CE001	44	3	43.56	32.14	26.67	22.6	43.95	7.73	0.18	0.05	0.13	43.45	32.55	27.44	23.07	44.01	7.456	0.169	0.057	0.133
02CE004	71	3	32.01	22.92	17.83	13.54	31.35	5.72	0.18	−0.05	0.1	31.94	23.16	18.3	14.25	31.42	5.47	0.174	−0.037	0.124
02CF005	32	3	0.149	0.107	0.092	0.084	0.164	0.037	0.228	0.196	0.09	0.153	0.12	0.109	0.103	0.165	0.029	0.178	0.22	0.122
02CF008	30	3	0.449	0.143	0.086	0.056	0.744	0.434	0.583	0.439	0.166	0.549	0.168	0.066	0.018	0.767	0.373	0.486	0.399	0.282
02CF009	32	3	0.02	0.01	0.003	0.001	0.02	0.01	0.41	0.34	0.23	0.019	0.0078	0.0037	0.0014	0.022	0.008	0.358	0.274	0.318
02CF011	20	3	2.363	1.739	1.46	1.263	2.414	0.448	0.186	0.101	0.116	2.375	1.836	1.602	1.44	2.431	0.401	0.165	0.069	0.014
02DB005	39	3	10.54	6.08	4.51	3.58	11.82	3.59	0.31	0.15	0.13	11.05	7.177	5.757	4.89	11.999	3.036	0.253	0.172	0.129
02DC007	53	3	0.06	0.005	0.001	0	0.38	0.34	0.9	0.8	0.55	0.0895	0.0086	0.0018	0.0003	0.401	0.339	0.846	0.733	0.476
02DD009	35	3	1.54	0.99	0.73	0.54	1.57	0.39	0.25	0.05	0.09	1.549	1.016	0.772	0.596	1.585	0.369	0.233	0.085	0.131
02DD016	11	3	2.78	1.08	0.73	0.59	4.39	2.22	0.51	0.54	0.37	3.454	1.906	1.566	1.424	4.76	1.973	0.415	0.486	0.292
02EA006	76	3	1.89	1.09	0.74	0.5	1.97	0.54	0.27	0.06	0.18	1.884	1.149	0.834	0.617	1.97	0.507	0.257	0.111	0.168
02EB014	10	3	1.096	0.624	0.52	0.477	1.493	0.634	0.425	0.434	0.196	1.22	0.805	0.711	0.671	1.548	0.535	0.345	0.448	0.211
04LD001	70	4	29.75	20.84	16.56	13.37	30.01	6.1	0.2	−0.01	0.09	29.55	21.08	17.11	14.2	29.95	5.821	0.194	0.009	0.107
04LG002	24	4	166.1	129.9	111	95.99	164.98	24.66	0.15	−0.02	0.06	167	134.6	117.5	103.8	165.8	21.71	0.131	−0.018	0.124
04MC001	36	4	80.38	64.52	55.07	46.71	78.55	9.85	0.13	−0.23	0.05	97.84	79.78	69.69	61.2	96.66	10.921	0.113	−0.039	0.232
04MD002	53	4	0.04	0.003	0.001	0	0.19	0.17	0.88	0.77	0.49	0.048	0.005	0.0011	0.0002	0.199	0.166	0.832	0.719	0.465
04MD004	14	4	0.58	0.42	0.34	0.29	0.58	0.12	0.2	−0.04	0.07	0.558	0.463	0.421	0.392	0.566	0.073	0.128	−0.02	−0.031
04ME004	30	4	155.7	127.6	115.6	107.4	159.1	20.47	0.13	0.07	0.14	156.4	130.3	119.2	111.6	159.6	19.31	0.121	0.064	0.094
Average			25.28	19.26	16.33	14.11						26.2	20.45	17.66	15.48					
Average/km^2			0.0028	0.0020	0.0014	0.0012						0.0029	0.0021	0.0016	0.0013					

KAMINISTIQUIA RIVER, STATION No.02AB004
MANN-KENDALL Tau=-0.221, S.L.=0.0096



EXCLUDED FROM THE STUDY

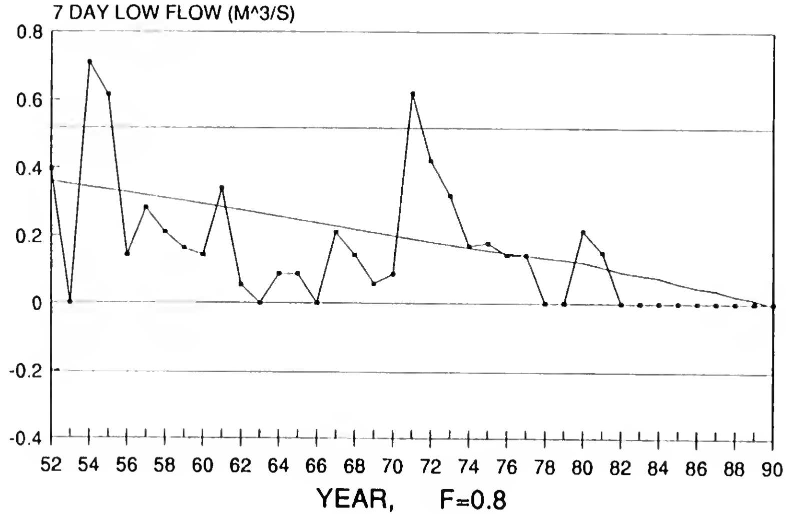
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 1



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.2

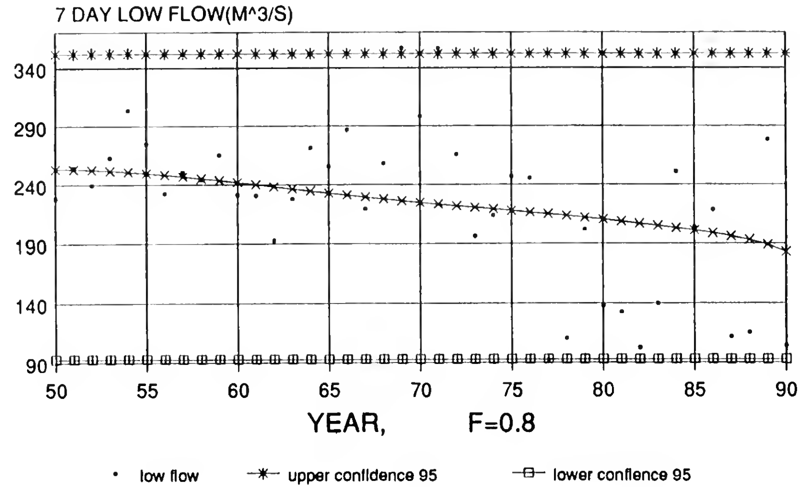
KASHABOWIE RIVER, STATION No.02AB013
MANN-KENDALL Tau=-0.422, S.L.=0.009



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.3

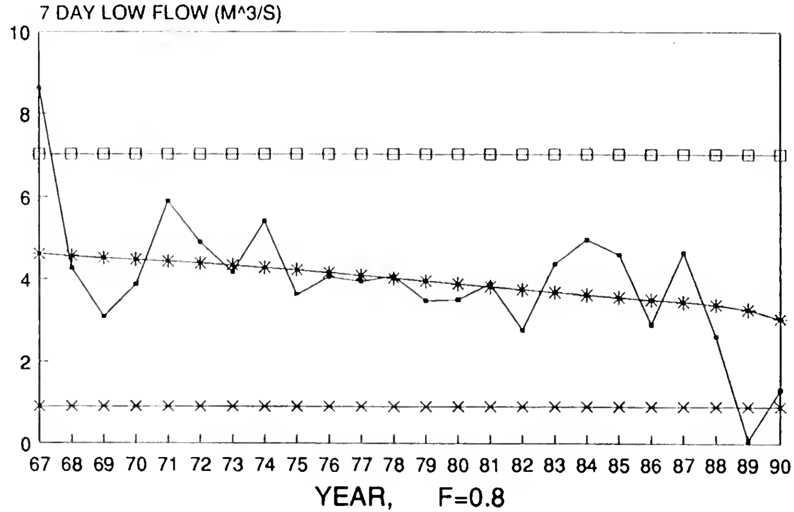
NIPIGON RIVER, STATION No. 02AD008
MANN-KENDALL Tau=-0.326, S.L.=0.005



EXCLUDED FROM THE STUDY

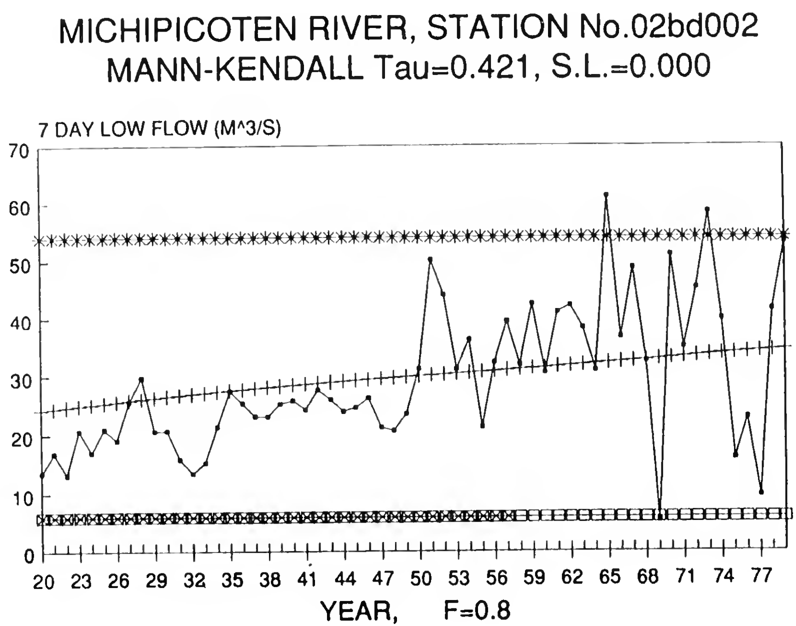
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.4

BLACK RIVER, STATION NO. 02BB002
MANN-KENDALL Tau=-0.348, S.L.=0.009



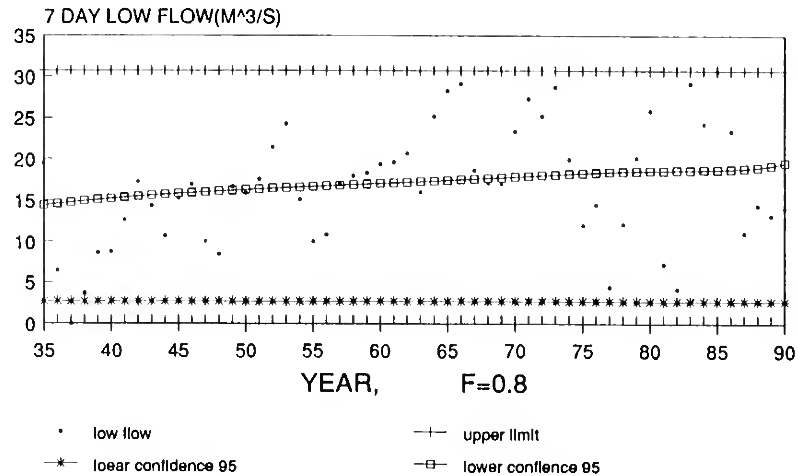
EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 5



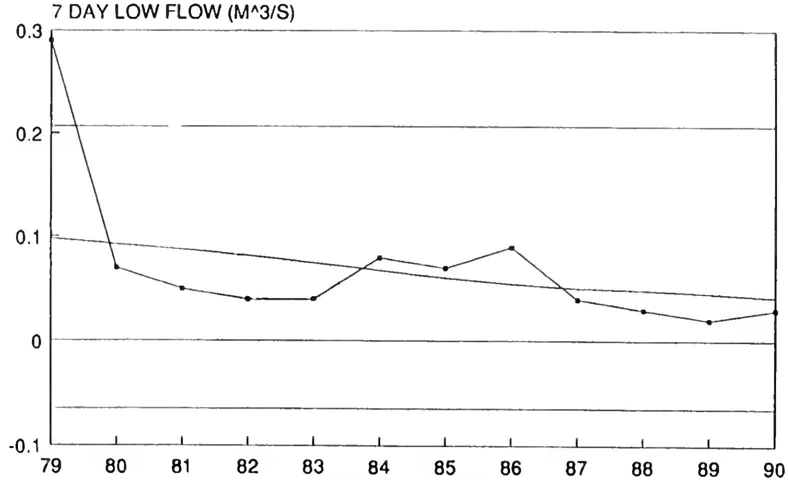
EXCLUDED FROM THE STUDY

MONTREAL RIVER, STATION No. 02BE002
MANN-KENDALL Tau=0.266, S.L.=0.000



EXCLUDED FROM THE STUDY

BIG CARP RIVER, STATION NO. 02BF004
MANN-KENDALL Tau=-0.50, S.L.=0.009



YEAR, F=0.8

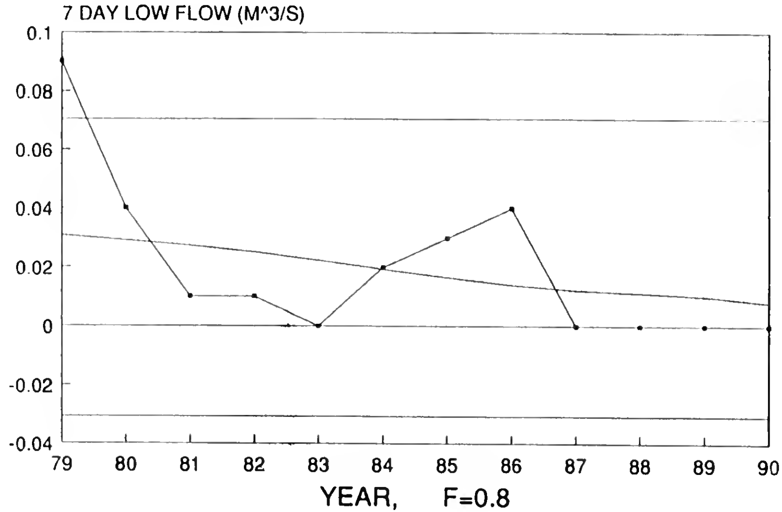
Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

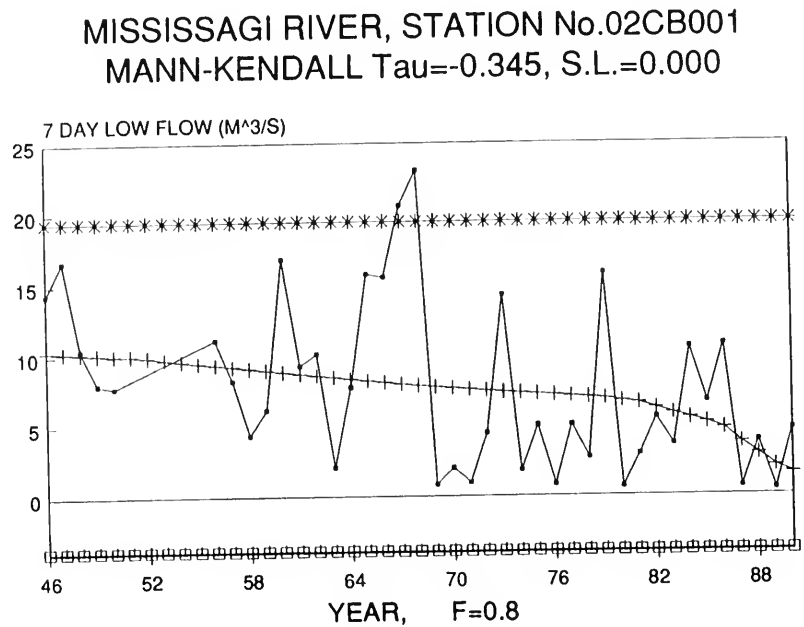
TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

FIGURE A.8

NORBERG CREEK, STATION NO. 02BF006
MANN-KENDALL Tau=-0.455, S.L.=0.007



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.9



EXCLUDED FROM THE STUDY

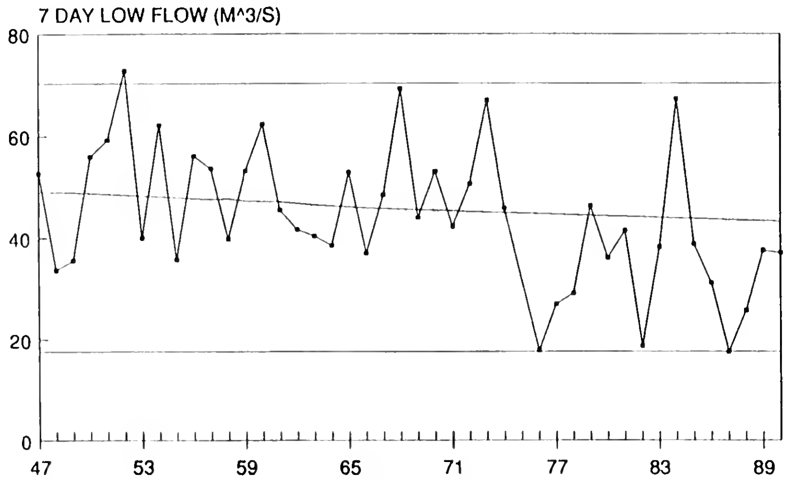
Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

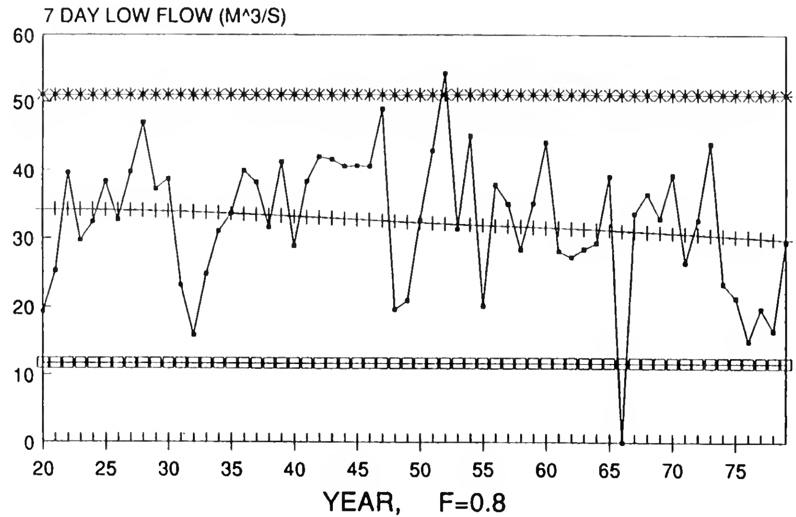
FIGURE A.10

SPANISH RIVER, STATION No.02CE001
MANN-KENDALL Tau=-0.254, S.L.=0.006



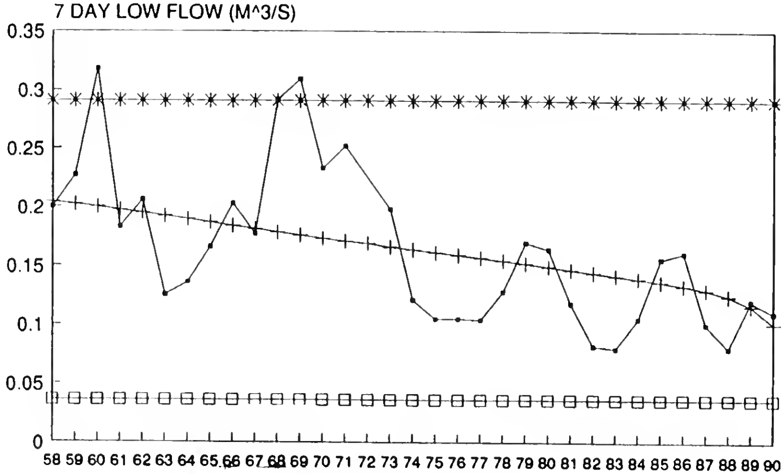
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 11

SPANISH RIVER, STATION No.02CE004
MANN-KENDALL Tau=-0.216, S.L.=0.021



EXCLUDED FROM THE STUDY

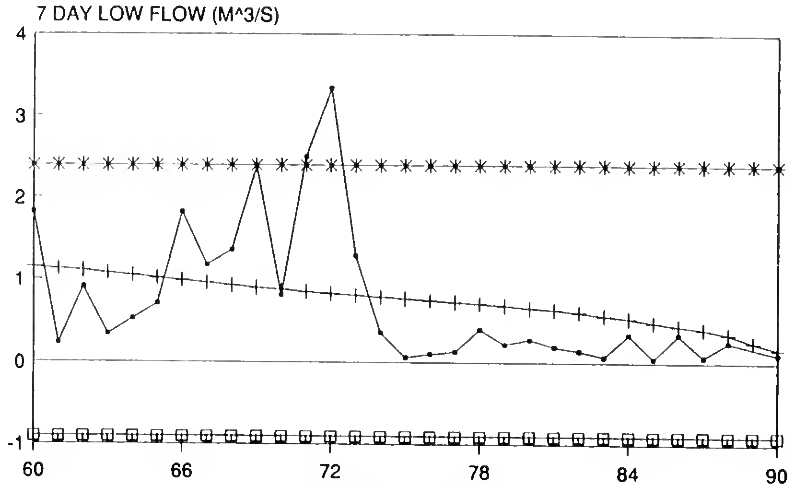
JUNCTION RIVER, STATION No.02CF005
MANN-KENDALL Tau=-0.462, S.L.=0.0004



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TRENDS ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 13

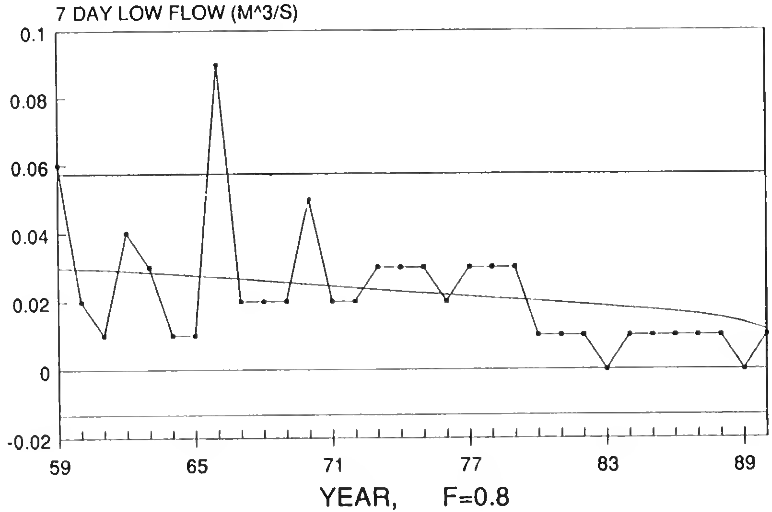
WHITSON RIVER, STATION No.02CF008
MANN-KENDALL Tau=-0.369, S.L.=0.002



EXCLUDED FROM THE STUDY

FIGURE A.14

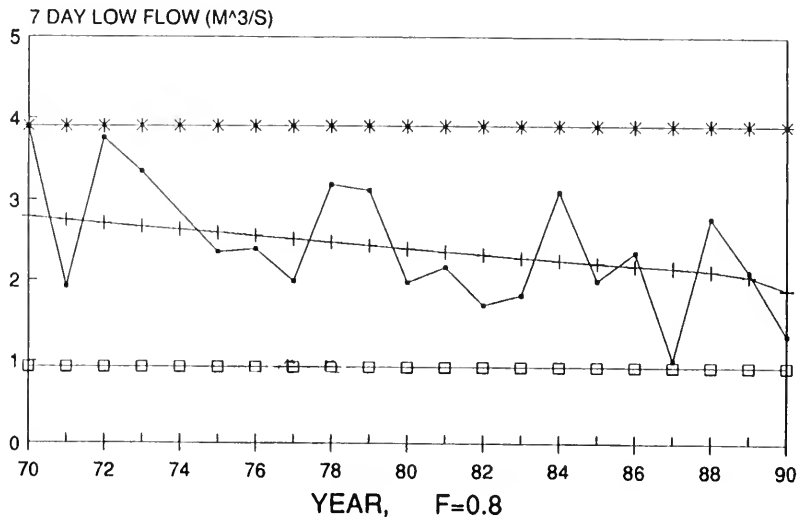
NOLIN CREEK, STATION No.02CF009
MANN-KENDALL Tau=-0.369, S.L.=0.003



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 15

VERMILION RIVER, STATION No.02CF011
MANN-KENDALL Tau=-0.384, S.L.=0.0025



TESTING STATION

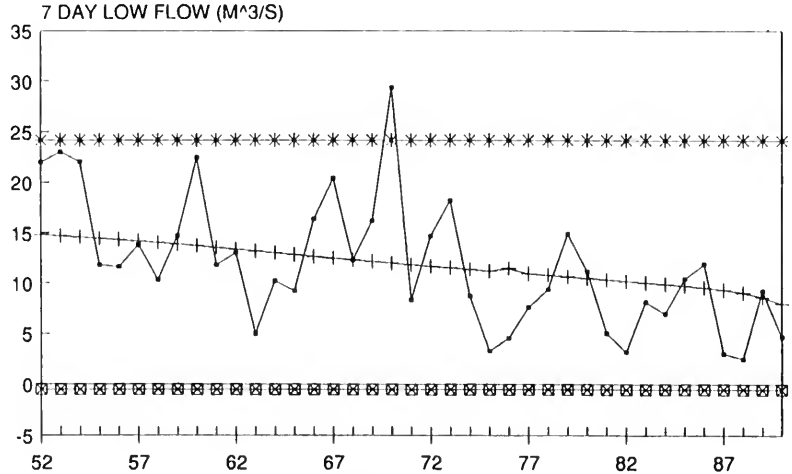
Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

FIGURE A.16

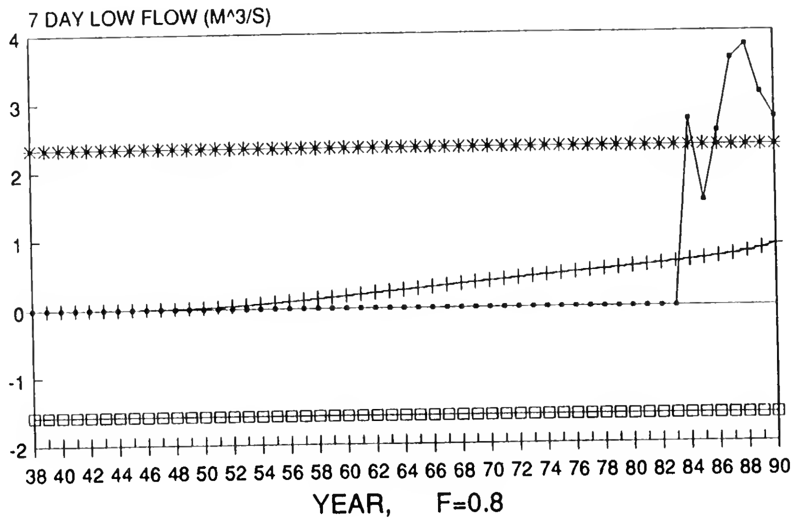
WANAPITEI RIVER, STATION No.02DB005
MANN-KENDALL Tau=-0.424, S.L.=0.0096



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.17

TEMAGAMI RIVER, STATION No.02DC007
MANN-KENDALL Tau=0.239, S.L.=0.0025

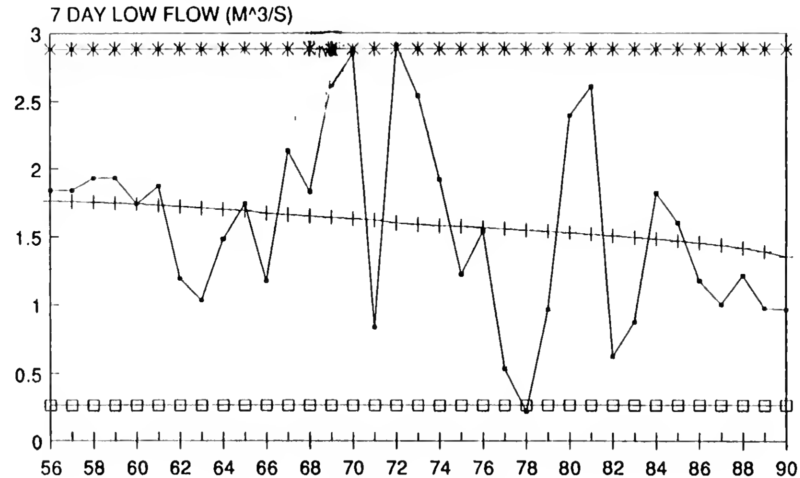


EXCLUDED FROM THE STUDY

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

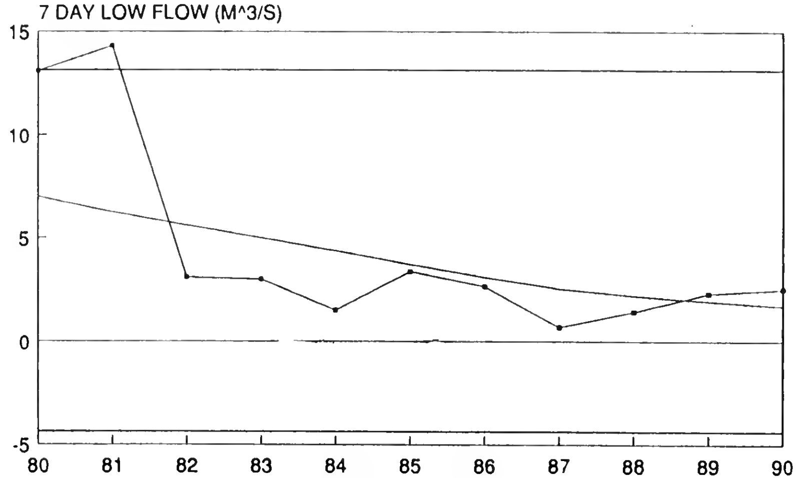
FIGURE A.18

SOUTH RIVER, STATION No.02DD009
MANN-KENDALL Tau=-0.25, S.L.=0.005



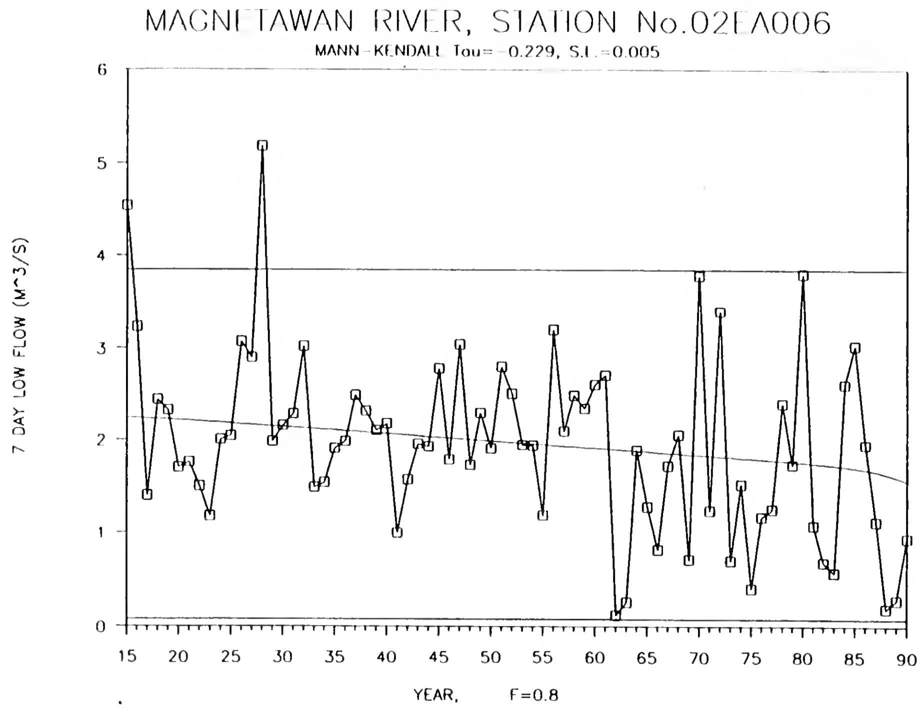
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.19

FRENCH RIVER, STATION No.02DD016
MANN-KENDALL Tau=-0.527, S.L.=0.005



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.20

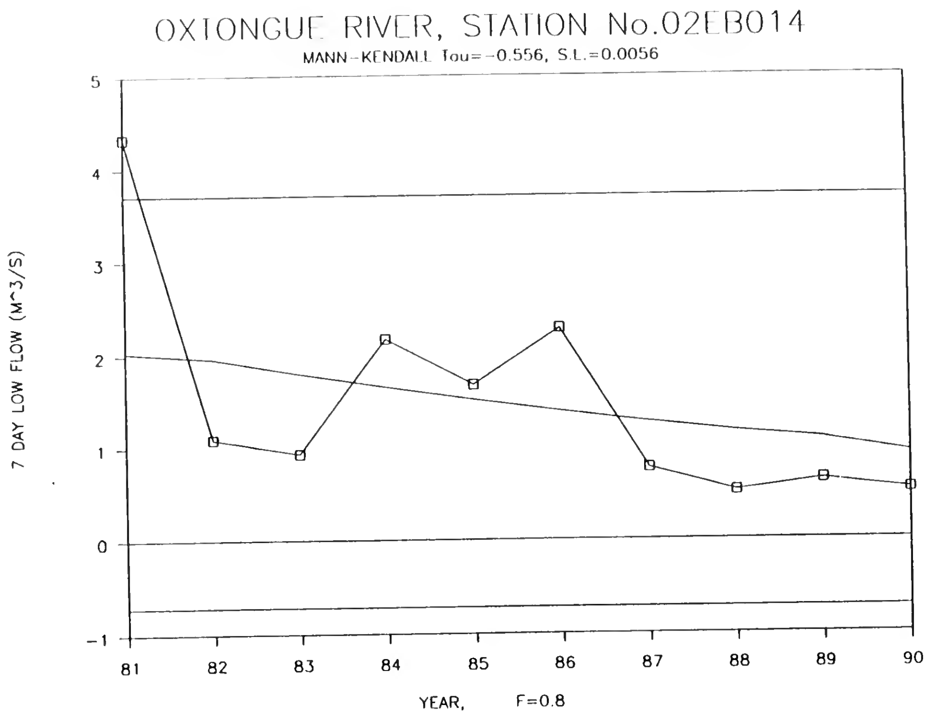


Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TRENDS ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

FIGURE A 21



EXCLUDED FROM THE STUDY

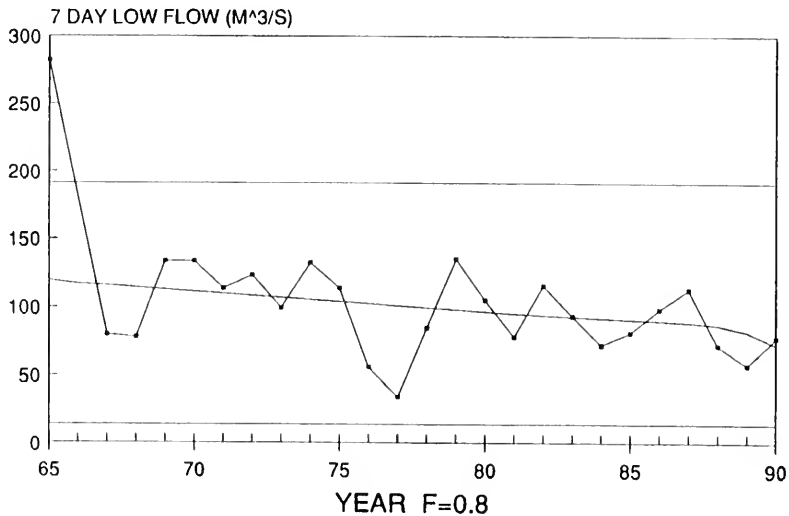
Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

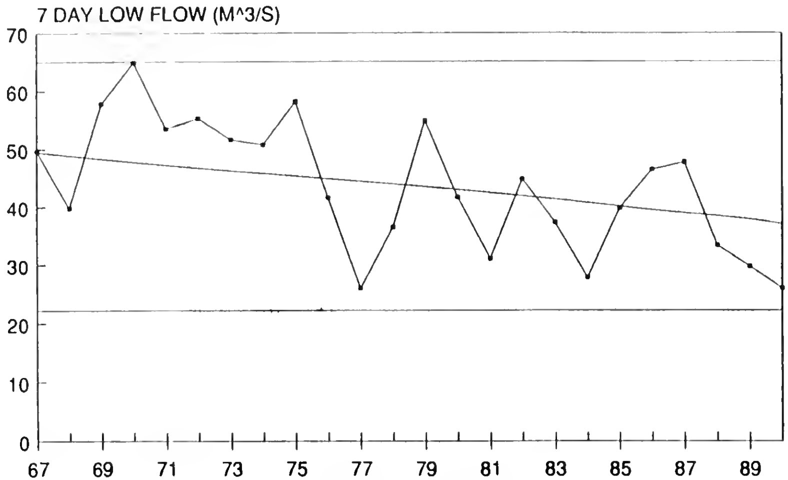
FIGURE A.22

SEVERN RIVER, STATION No.=04CA002
MANN-KENDALL Tau=-0.337, S.L.=0.0012



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 23

WINDIGO RIVER, STATION No.04CB001
MANN-KENDALL Tau=-0.428, S.L.=0.030



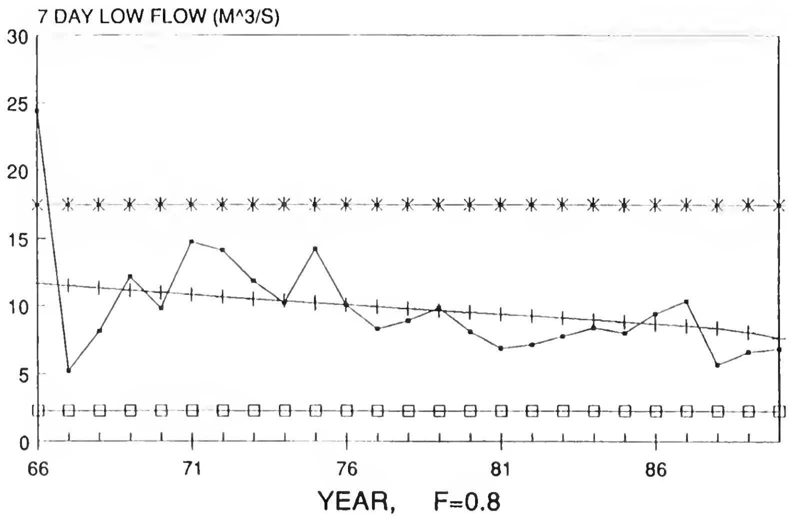
Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

FIGURE A.24

PIPESTONE RIVER, STATION No.04DA001
MANN-KENDALL Tau=-0.413, S.L.=0.02



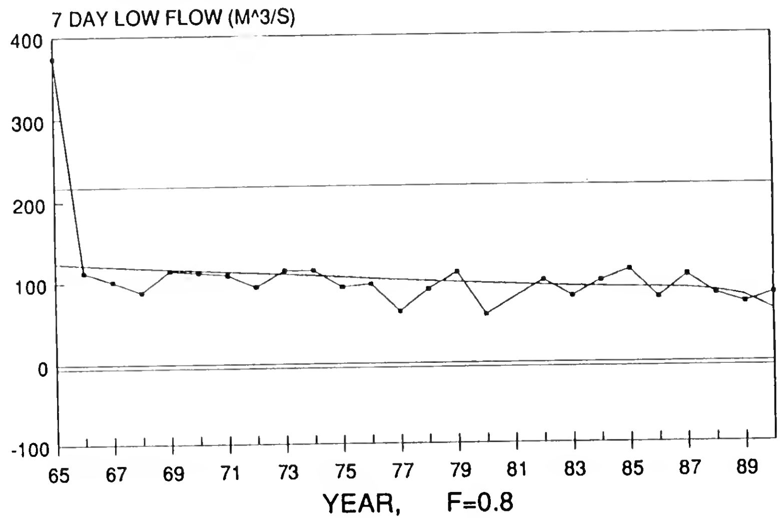
Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

FIGURE A 25

WINISK RIVER, STATION No.04DC001
MANN-KENDALL Tau=-0.383, S.L.=0.009



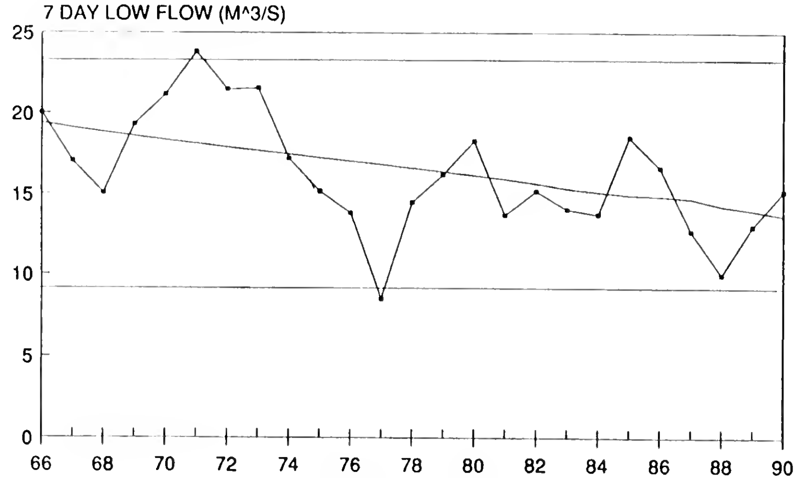
Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

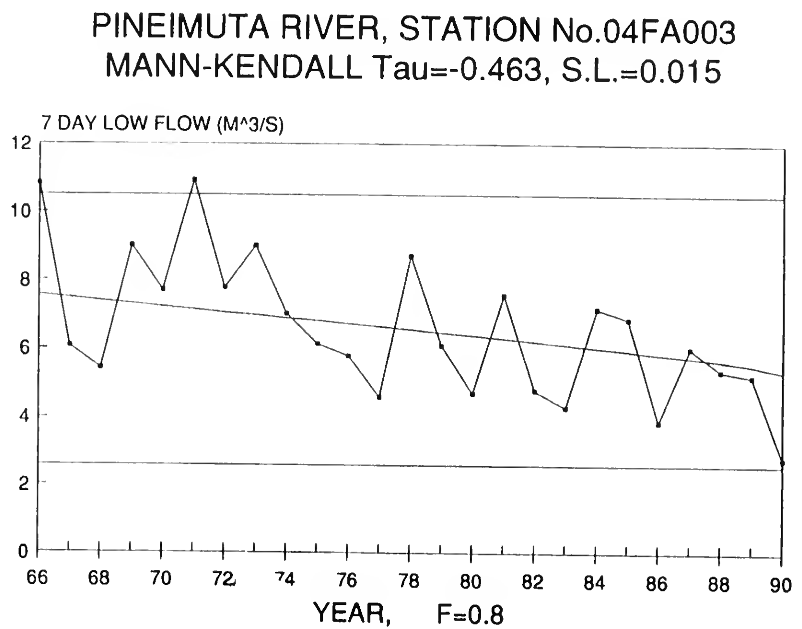
REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

FIGURE A.26

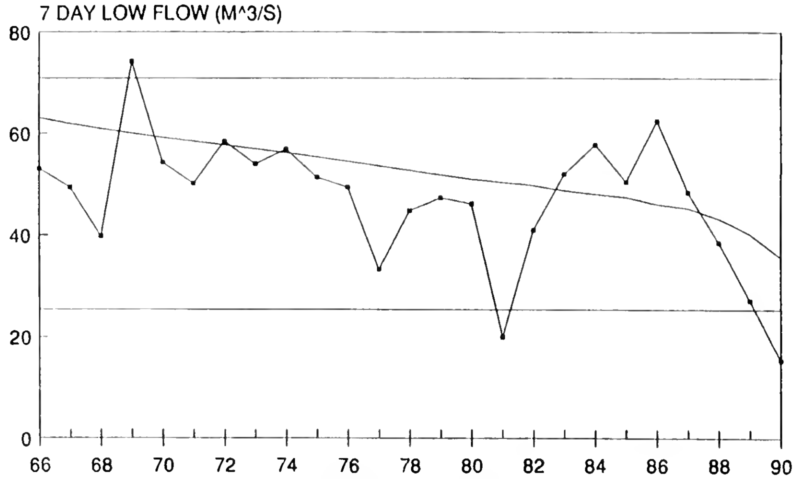
OTOSKWIN RIVER, STATION No.04FA001
MANN-KENDALL Tau=-0.423, S.L.=0.012





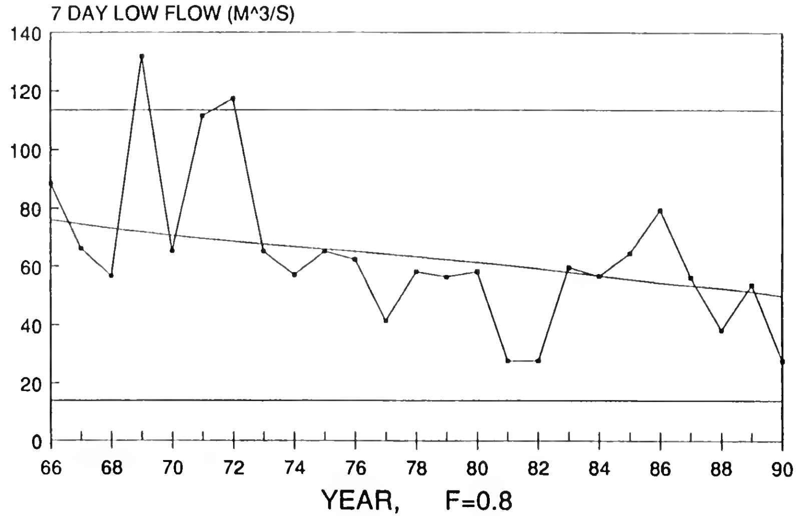
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.28

ATTAWAPISKAT RIVER, STATION No.04FB001
MANN-KENDALL Tau=-0.301, S.L.=0.002



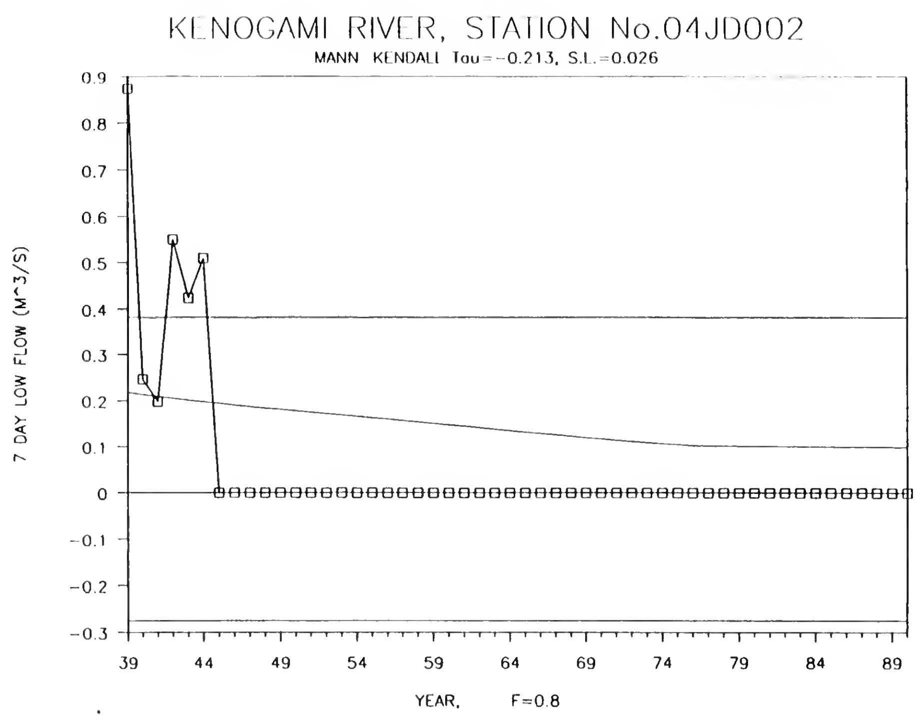
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 29

ALBANY RIVER, STATION No.04GD001
MANN-KENDALL Tau=-0.47, S.L.=0.003



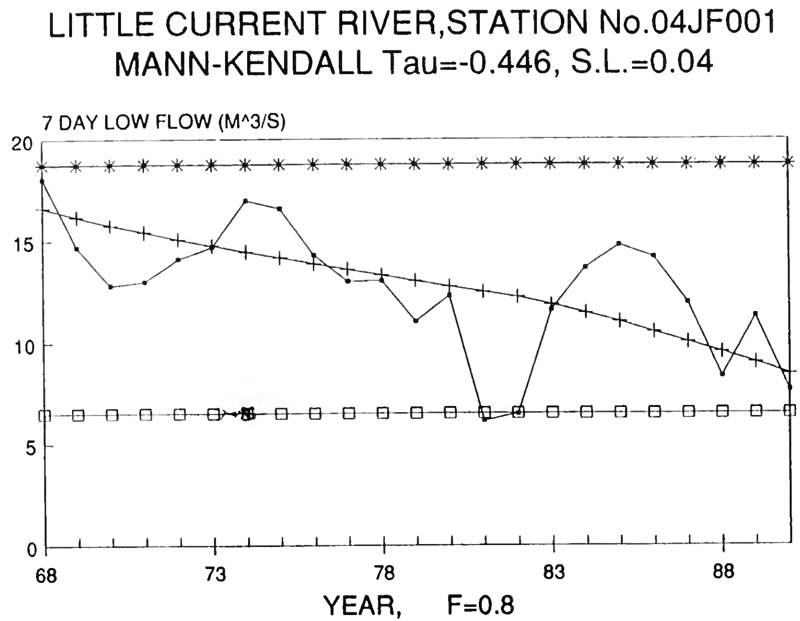
TREND ANALYSIS STATISTICS AND
LOCALLY WEIGHTED REGRESSION
SMOOTH

FIGURE A.30



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 31



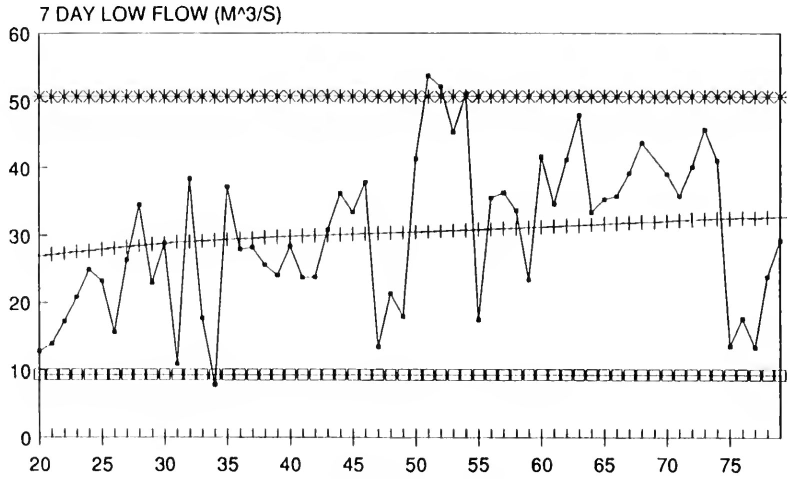
Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

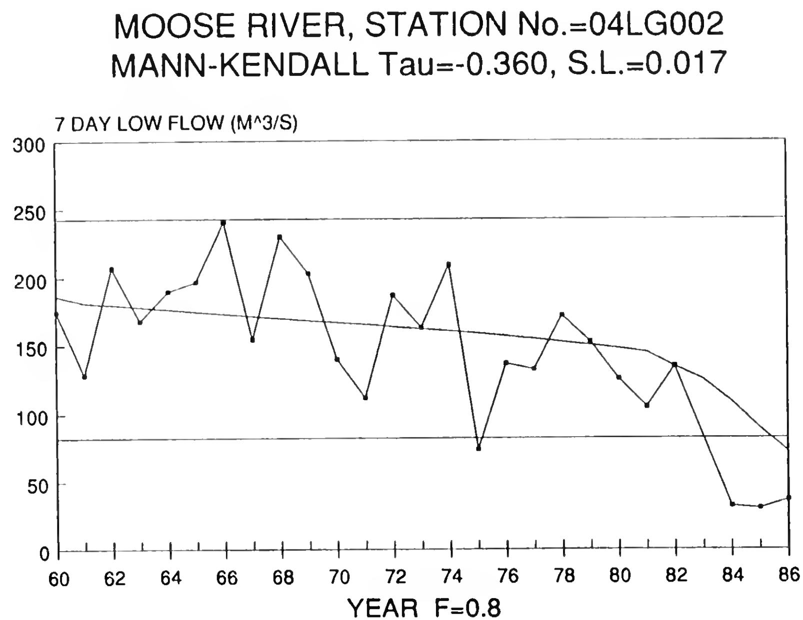
FIGURE A.32

GROUNDHOG RIVER, STATION No.=04LD001
MANN-KENDALL Tau=0.221, S.L.=0.012



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 33



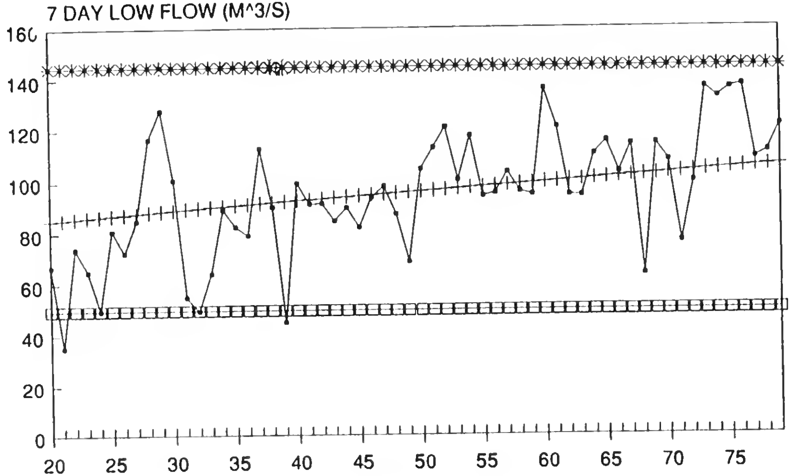
Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

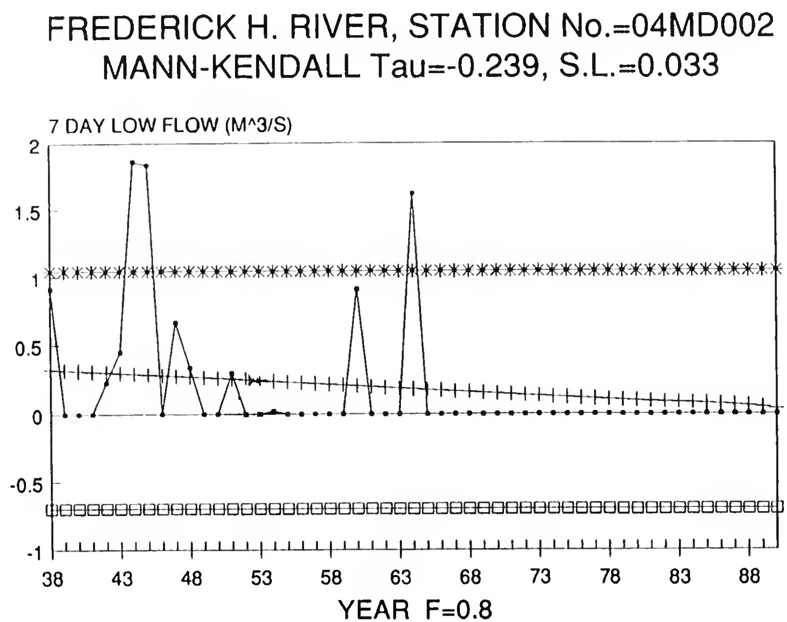
FIGURE A.34

ABITIBI RIVER, STATION No.=04MC001
MANN-KENDALL Tau=0.452, S.L.=0.012



EXCLUDED FROM THE STUDY

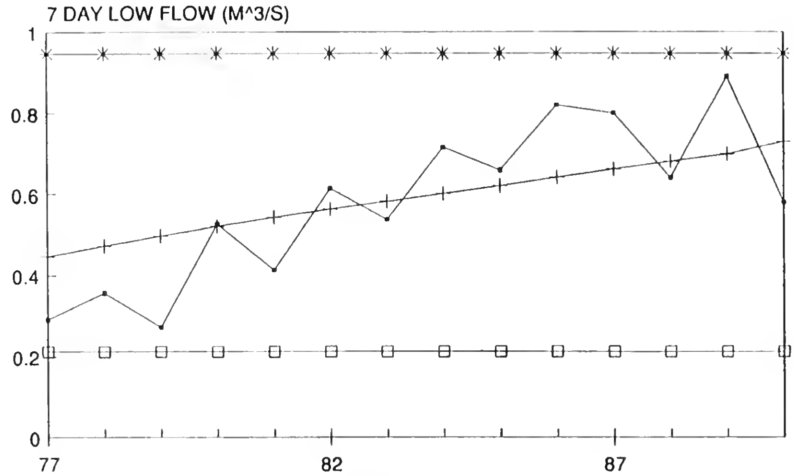
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.35



EXCLUDED FROM THE STUDY

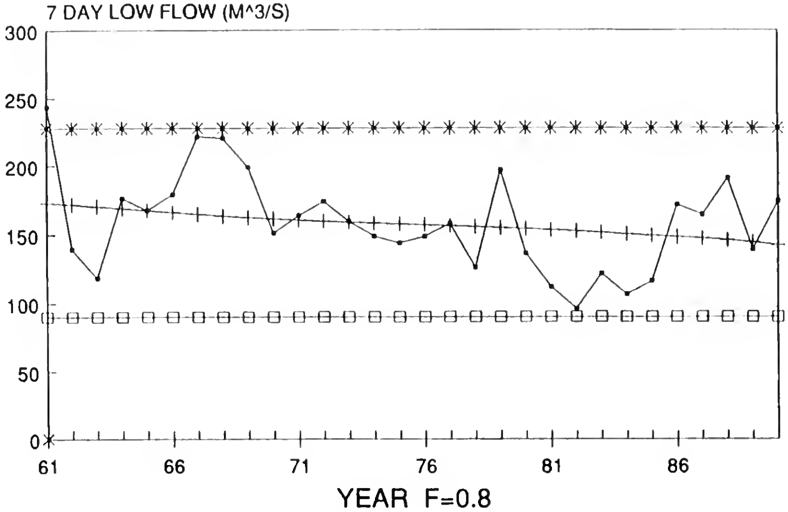
FIGURE A.36

PORCUPINE RIVER, STATION No.=04MD004
MANN-KENDALL Tau=0.626, S.L.=0.000



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.37

ABITIBI RIVER, STATION No.=04ME004
MANN-KENDALL Tau=-0.269, S.L.=0.0073



TESTING STATION

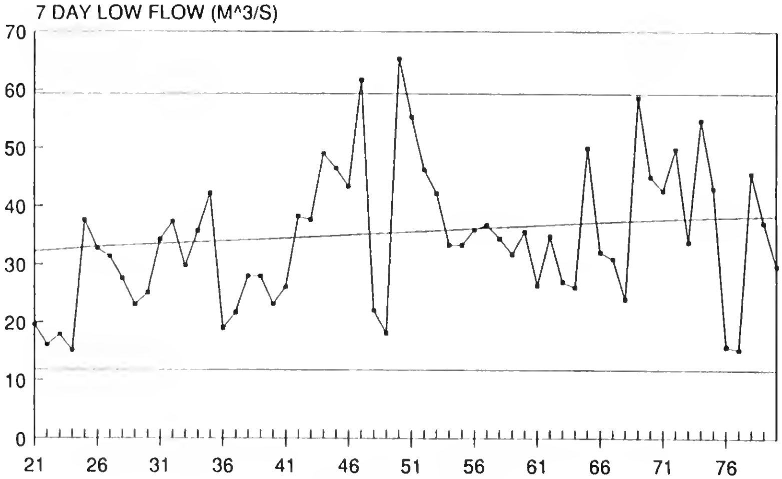
Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH

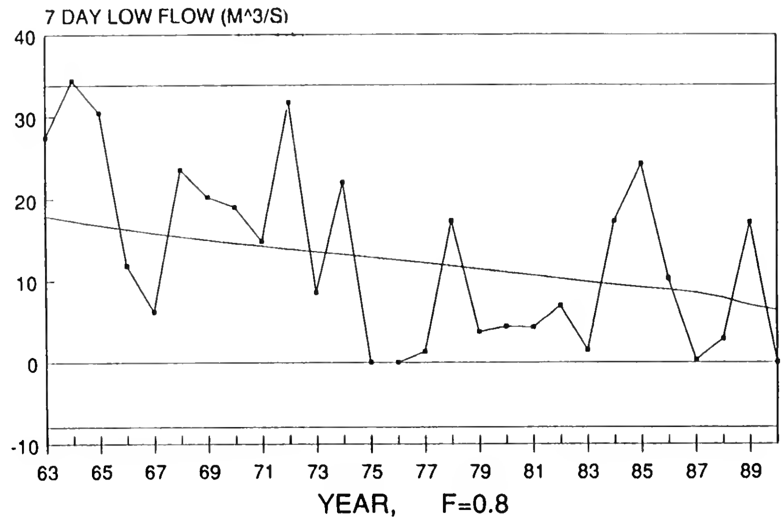
FIGURE A.38

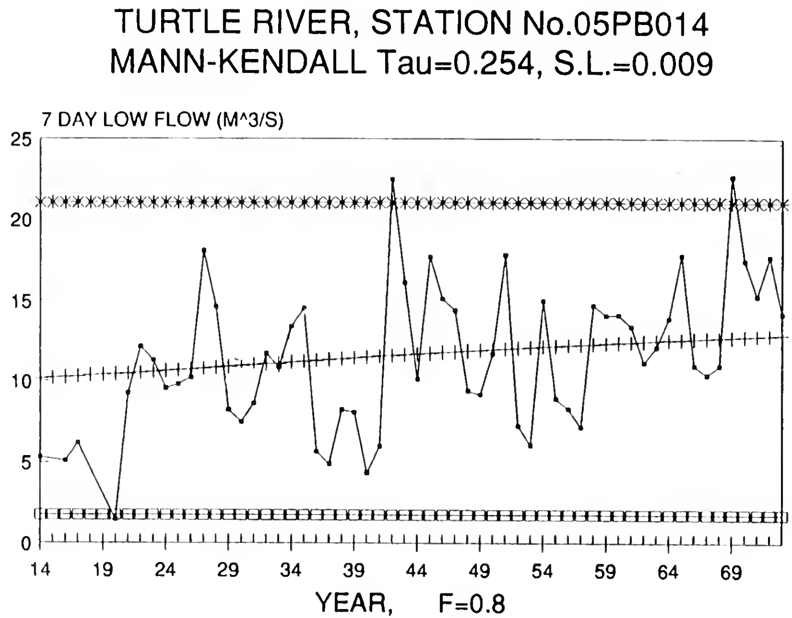
NAMAKAN RIVER,STATION No.05PA006
MANN-KENDALL Tau=0.242, S.L.=0.006



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 39

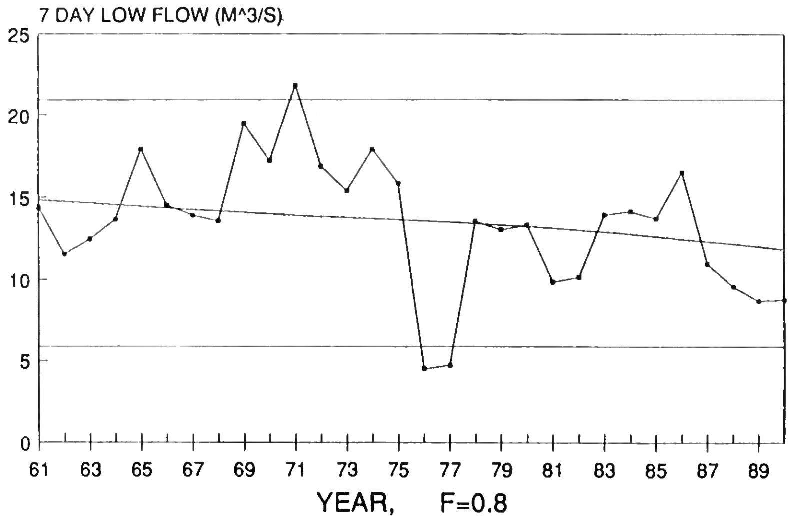
SEINE RIVER, STATION No.05PB009
MANN-KENDALL Tau=-0.373, S.L.=0.08





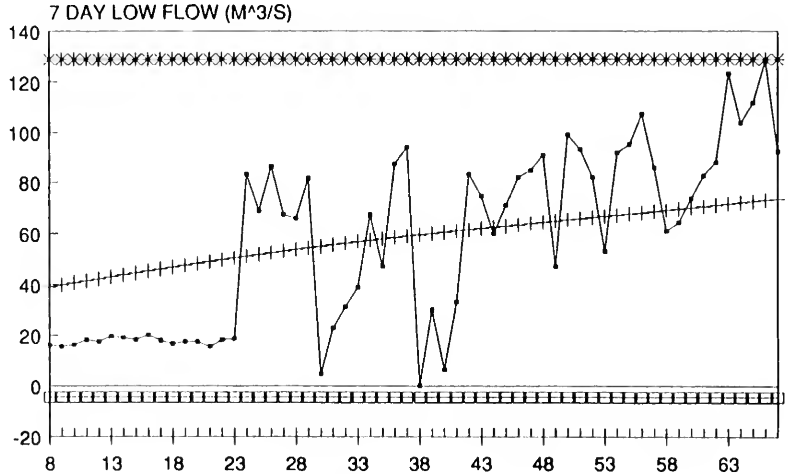
EXCLUDED FROM THE STUDY

STURGEON RIVER, STATION No.05QA004
MANN-KENDALL Tau=-0.274, S.L.=0.01

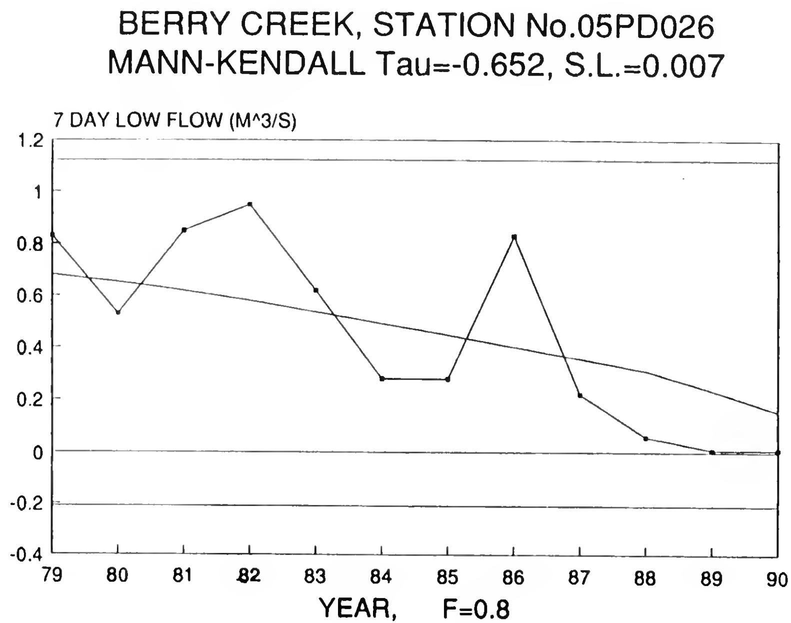


EXCLUDED FROM THE STUDY

LAKE OF WOODS RIVER, STATION No.05PE006
MANN-KENDALL Tau=0.411, S.L.=0.000

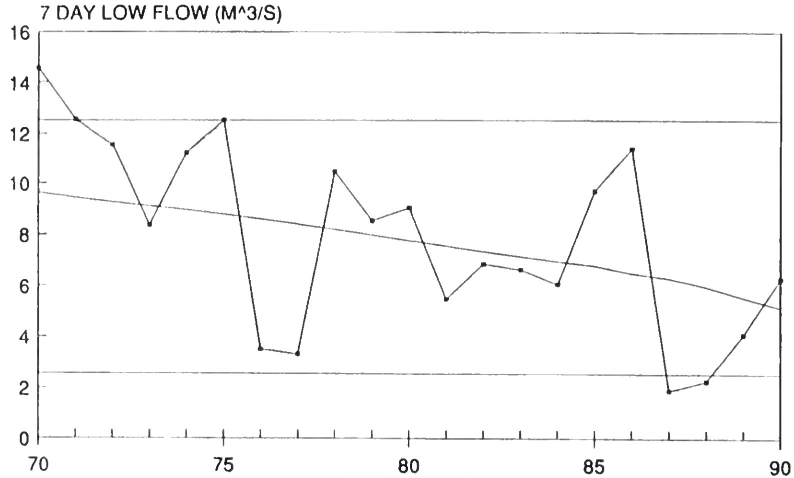


EXCLUDED FROM THE STUDY



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.44

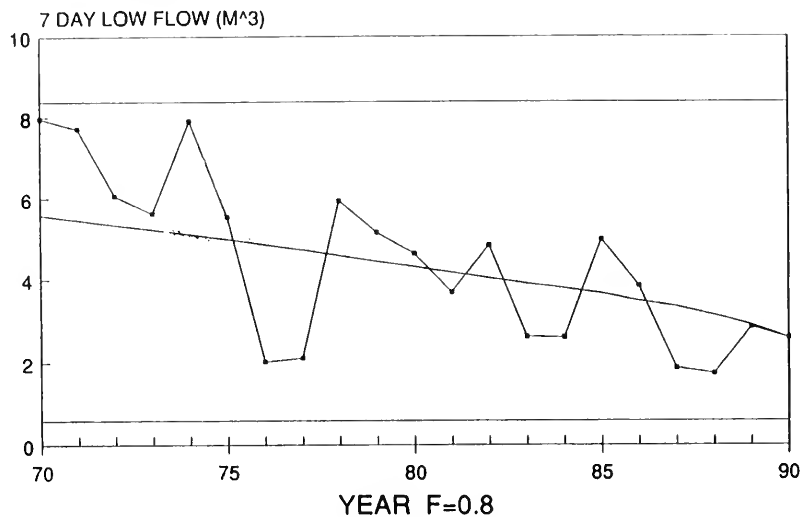
TROUTLAKE RIVER, STATION No.05QC003
MANN-KENDALL Tau=-0.448, S.L.=0.012



EXCLUDED FROM THE STUDY

Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A 45

CEDAR RIVER, STATION No.05QE008
MANN-FENDALL Tau=-0.581, S.L.=0.005



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	TREND ANALYSIS STATISTICS AND LOCALLY WEIGHTED REGRESSION SMOOTH FIGURE A.46

APPENDIX B

LOW FLOW FREQUENCY ANALYSIS

APPENDIX B
LOW FLOW FREQUENCY ANALYSIS

B.1 Frequency Analysis - Weibull Distribution

The Weibull distribution has been widely adopted as the parent distribution of low flows on most Canadian rivers (Cumming Cockburn Limited, 1990). The present study has also confirmed that all of the stations, with one exception, were best fitted by the three-parameter Weibull distribution. Thus, only the W3 distribution is described here briefly.

The probability density function of the W3 distribution is:

$$\phi(x) = \frac{a}{u-e}\left[\frac{x-e}{u-e}\right]^{a-1} \exp\left[-\left[\frac{x-e}{u-e}\right]^{a}\right] \tag{B - 1}$$

Where e is the lower boundary parameter, u is the characteristic drought, and a is the shape parameter. The density function can be integrated to the following form:

$$F(X) = 1 - \exp\left[-\left[\frac{x-e}{u-e}\right]^{a}\right] \tag{B - 2}$$

where F(X) is the probability of nonexceedance of X and is the inverse of the return period of nonexceedance, y. X can be obtained by rearranging equation (3-2) to give:

$$X = e + (u-e)\ \{\ -\ln[1-F(X)]\ \}^{\frac{1}{a}} \tag{B - 3}$$

B.2 Frequency Analysis - L-Moments

Moment based methods have long been established in statistics for estimating distribution parameters from available sample data sets. Conventional moments are not always satisfactory in two major respects. They do not always impart easily interpreted information about the shape of a distribution (especially Skew and Kurtosis), and estimates of parameters of distributions fitted by the moments are often less accurate than those obtained by other methods such as maximum likelihood.

An alternative to conventional moments is L-moments. These can be estimated by linear combinations of order statistics. Theoretically, L-moments are able to characterize a wider range of distributions than conventional moments. Practically, they are less subject to bias in

estimation, and they approximate their asymptotic normal distribution more closely. The main advantage of L-moments over conventional moments is that L-moments suffer less from the effects of sampling variability; they are more robust to outliers in the data.

If the order statistics of a random sample of size n that has been drawn from the distribution of a real valued random variable X with cumulative distribution function F(X) and quantile function X(F) are:

$$X_{1:n} \leq X_{2:n} \leq \ldots \leq X_{n:n} \qquad \text{(B - 4)}$$

then the L-moments for r = 1, 2, ... are:

$$\beta_r = r^{-1} \sum_{k=0}^{r-1} (-1)^k \binom{r-1}{k} EX_{r-k:r} \qquad \text{(B - 5)}$$

The expectation of an order statistic is:

$$EX_{j:r} = \frac{r!}{(j-1)!(r-j)!} \int X[F(X)]^{j-1} \, [1-F(X)]^{r-j} \, dF(X) \qquad \text{(B - 6)}$$

The first L-moment is the mean of the distribution. The second is a measure of scale or dispersion. Standardizing higher moments r > 2:

$$\tau_r = \frac{\beta_r}{\beta_2} \qquad \text{(B - 7)}$$

and defining a function of L-moments analogous to the coefficients of variation (CV):

$$L - CV = \frac{\beta_2}{\beta_1} \qquad \text{(B - 8)}$$

$$L - Skew = \tau_3 = \frac{\beta_3}{\beta_2} \qquad \text{(B - 9)}$$

$$L - Kurtosis = \tau_4 = \frac{\beta_4}{\beta_2} \qquad \text{(B - 10)}$$

To fit the Weibull distribution, by L-moments the values of the three parameters, that is a, e and u, should be estimated. Hosking et al (1985) suggested the approximate solution for the shape parameter as:

$$k = \frac{1}{a} = 7.8590 \; C + 2.9554 \; C^2 \qquad \text{(B - 11)}$$

where:

$$C = \frac{(2\beta_1 - \beta_0)}{(3\beta_2 - \beta_0)} - \frac{\log 2}{\log 3}$$

where β_0, β_1 and β_2 are defined in equation (B-5). And let:

$$\psi = \frac{\beta_2 k}{(1-2^{-k})\ \Gamma\ (1+k)}$$

where β_2 is the second L-moments computed by equation (B - 5). Thus, the characteristic drought u is calculated by:

$$u = \beta_1 - \psi \{ 1 - \Gamma\ (1+k) \} / k \qquad \text{(B - 12)}$$

Finally, the lower boundary parameter e can be estimated using the above information:

$$e = u - \psi a \qquad \text{(B - 13)}$$

The low flow statistics calculated by the conventional moments (-1986) and by the L-moments (1990) are summarized in Table B.1. In general, the L-moments method gives conservative estimations of low flow statistics.

Table B.2 presents the summary of 1, 3, 7, 15, and 30 days duration low flow statistics and Table B.3 provides the a, e, and u parameters of Weibull III distribution for 1, 3, 7, 15, and 30 days duration low flow of the stations in Northern Ontario. The parameters may be applied to estimate any low flow statistics.

Figures B.1 to B.12 show the distribution patterns of L-moments ratios (i.e. L-CS vs. L-CV and L-CS vs. L-CK) for Northern Ontario and its Sub-regions.

This analysis appears to be consistent with Hosking (1989), who plotted the L-moments ratios for some common distributions by Monte Carlo simulation using 100, 000 simulated samples. Comparing Figures B.1 to B.12 with the L-moments ratios of Weibull III distribution (theoretical) confirms that the low flow records could be best fitted by Weibull III distribution.

NORTHWESTERN REGION

Station	# of	Region	CONVENTIONAL MOMENTS (–1986)				L–MOMENTS (–1990)													
Number	Years	Code	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	Q Mean	dQ	CV	CS	CK	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda 1	lambda 2	L–CV	L–CS	L–CK
02AA001	68	3	2.105	1.292	0.909	0.626	2.12	0.92	0.44	0.67	4.52	2.07	1.27	0.9	0.62	2.12	0.5	0.24	0.1	0.21
02AB006	64	3	25.45	18.65	15.49	13.18	25.11	8.32	0.33	0.35	2.89	24.59	17.76	14.68	12.48	25.11	4.74	0.19	0.06	0.1
02AB009	34	3	4.629	3.12	2.641	2.379	5.04	2.24	0.45	0.91	3.63	4.49	3.07	2.62	2.37	5.04	1.25	0.25	0.2	0.1
02AB010	68	3	21.45	15.45	12.86	11.08	21.82	7.44	0.34	0.44	2.85	21.12	15.23	12.71	10.98	21.82	4.24	0.19	0.1	0.09
02AB014	19	3	0.071	0.032	0.018	0.01	0.08	0.05	0.63	1.08	6.21	0.075	0.03	0.016	0.004	0.08	0.03	0.34	0.12	0.28
02AB015	14	3	0.518	0.341	0.28	0.245	0.57	0.26	0.46	1.02	4.88	0.52	0.34	0.28	0.24	0.57	0.15	0.26	0.22	0.18
02AB016	14	3	0.056	0.021	0.007	0	0.06	0.05	0.77	0.27	2.98	0.056	0.02	0.007	0	0.06	0.03	0.45	0.08	0.04
02AB017	11	3	N/A	N/A	N/A	N/A	0.2	0.1	0.53	0.9	4.12	0.17	0.11	0.08	0.07	0.2	0.06	0.3	0.25	1.18
02AC001	20	3	0.641	0.41	0.314	0.25	0.7	0.32	0.45	0.54	3.23	0.67	0.43	0.33	0.26	0.7	0.18	0.26	0.14	0.09
02AD010	20	3	0.826	0.636	0.558	0.506	0.88	0.23	0.27	–0.18	2.89	0.88	0.69	0.59	0.51	0.88	0.14	0.15	–0.06	0.07
02AE001	17	3	0.758	0.543	0.417	0.308	0.92	0.55	0.6	2.78	13.87	0.81	0.48	0.37	0.31	0.92	0.24	0.26	0.31	0.51
02BA002	21	3	2.659	2.056	1.831	1.693	2.7	0.8	0.3	0.45	2.38	2.54	2.003	1.82	1.71	2.7	0.46	0.171	0.14	0.003
02BA003	19	3	2.778	2.344	2.178	2.074	2.922	0.839	0.287	1.204	5.809	2.79	2.2	1.97	1.83	2.922	0.461	0.158	0.21	0.212
02BB002	24	3	4.01	3.382	3.12	2.945	3.965	1.595	0.402	0.349	6.774	3.928	2.489	1.768	1.21	3.965	0.835	0.211	0.005	0.357
02BB003	21	3	7.353	5.586	4.893	4.448	7.474	2.205	0.295	0.279	2.759	7.115	5.504	4.896	4.515	7.474	1.283	0.172	0.063	0.054
04CA002	14	1	N/A	N/A	N/A	N/A	102.6	46.21	0.45	2.43	12.74	95.44	63.48	51.48	44.03	102.59	22.2	0.22	0.23	0.289
04CA003	24	1	0.635	0.425	0.315	0.228	0.64	0.26	0.41	0.46	4.28	0.62	0.4	0.3	0.23	0.64	0.15	0.23	0.06	0.22
04CB001	24	1	45.27	36.23	31.72	28.74	43.58	11.16	0.26	–0.02	2.47	42.93	34.06	30.06	27.2	43.58	6.54	0.15	–0.01	0.03
04CC001	19	1	173.1	134.7	115.8	101.2	168.6	44.2	0.26	0.07	2.87	165.2	130.6	115.5	104.9	168.6	25.86	0.15	0.02	0.08
04CD002	20	1	13.48	11.98	11.48	11.2	15.17	7.12	0.47	3.82	19.31	12.6	10.61	10.27	10.15	15.17	2.61	0.17	0.6	0.59
04CE002	23	1	24.77	21.09	19.08	17.4	23.62	4.4	0.19	–0.04	3.16	23.62	19.92	18.07	16.65	23.62	2.54	0.11	–0.03	0.1
04DA001	25	1	9.395	7.402	6.562	5.994	9.88	3.96	0.4	2.21	10.22	8.98	6.72	6.02	5.64	9.88	1.97	0.2	0.32	0.28
04DB001	25	1	16.75	13.76	12.62	11.91	17.73	5.86	0.33	2.05	8.93	16.26	12.81	11.76	11.21	17.73	2.91	0.16	0.3	0.33
04DC001	14	1	N/A	N/A	N/A	N/A	106.1	58.07	0.55	4.36	24.2	86.23	64.89	60.45	58.67	106.1	19.88	0.19	0.427	0.533
04DC002	24	1	2.468	1.721	1.449	1.283	2.7	1.07	0.4	0.2	2.97	2.62	1.77	1.4	1.13	2.7	0.62	0.23	0.03	0.09
04FA001	25	1	16.79	13.67	12.06	10.77	16.91	5.58	0.33	2.08	10.36	16.05	12.14	10.67	9.75	16.91	2.78	0.16	0.26	0.31
04FA002	24	1	3.046	2.031	2.173	1.998	3.07	0.73	0.24	0.71	3.94	3	2.43	0.19	2.02	3.07	0.41	0.13	0.15	0.16
04FA003	25	1	6.387	5.018	4.507	4.191	6.55	2.06	0.31	0.51	3.35	6.38	4.74	4.03	3.54	6.55	1.18	0.18	0.12	0.13
04FB001	24	1	50.88	43.46	39.94	37.32	48.11	11.88	0.25	–0.72	5.46	48.93	38.32	32.23	26.99	48.11	6.41	0.13	–0.14	0.3
04FC001	23	1	57.13	49.1	46.42	44.89	57.96	12.04	0.208	1.276	6.515	55.27	47.64	45.15	43.77	57.96	6.464	0.112	0.152	0.141
04GA002	23	3	N/A	N/A	N/A	N/A	14.02	8.43	0.6	–0.56	2.66	13.51	6.5	3.33	1.05	14.02	4.82	0.34	0.15	0.01
04GB004	20	3	N/A	N/A	N/A	N/A	41.57	8.3	0.2	–1.01	5.16	42.84	35.44	30.65	26.13	41.57	4.58	0.11	–0.17	0.22
04GC002	16	1	16.84	11.58	8.897	6.795	17.74	6.93	0.39	–0.03	3.79	17.56	11.91	9.22	7.21	17.74	3.92	0.22	–0.05	0.2
04GD001	22	1	62.21	43.29	36.11	31.63	55.98	15.48	0.28	–0.34	3.89	56.57	43.22	36.07	30.23	55.98	8.42	0.15	–0.11	0.25
04JA002	37	1	10.23	7.24	6.647	5.905	10.61	3.18	0.3	0.18	2.93	10.37	7.83	6.71	5.92	10.61	1.32	0.17	0.02	0.11
04JC002	41	1	4.305	3.108	2.531	2.098	4.45	1.45	0.33	0.24	3.11	4.41	3.18	2.59	2.15	4.45	0.82	0.19	0.06	0.15
04JC003	37	1	6.736	5.234	4.393	3.684	6.67	1.7	0.26	–0.44	3.48	6.8	5.3	4.44	3.71	6.67	0.96	0.15	–0.07	0.14
04JF001	22	1	N/A	N/A	N/A	N/A	13.53	6.22	0.46	2.97	15.58	12.18	8.59	7.44	6.8	13.53	2.71	0.2	0.24	0.45
05PA006	70	2	34.5	24.95	21.04	18.44	35.54	12.22	0.34	0.59	3.05	34.05	24.59	20.74	18.18	35.54	6.85	0.19	0.1	0.16
05PA012	64	2	10.15	6.566	4.897	3.679	10.35	4.17	0.4	0.35	3.54	10.15	6.63	4.98	3.77	10.35	2.33	0.23	0.06	0.18
05PB009	28	2	N/A	N/A	N/A	N/A	12.94	10.84	0.84	0.44	2.32	10.39	3.73	1.62	0.47	12.94	6.26	0.48	0.14	–0.02

TABLE B.1(a)

SUMMARY OF LOW FLOW FREQUENCY ANALYSIS

NORTHWESTERN REGION

Station Number	# of Years	Region Code	CONVENTIONAL MOMENTS (-1986) $7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	L-MOMENTS (-1990) Q Mean	dQ	CV	CS	CK	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda 1	lambda 2	L-CV	L-CS	L-CK
05PB018	12	2	N/A	N/A	N/A	N/A	1.31	0.7	0.53	0.89	3.93	1.16	0.71	0.57	0.48	1.31	0.4	0.3	0.24	0.1
05PC018	11	2	146.2	106.1	87.06	72.86	145.84	46.62	0.32	0.328	3.091	144	104.5	85.99	72.34	145.84	26.46	0.181	0.071	0.13
05PC019	30	2	119.2	79.04	59.72	45.21	121.27	50.52	0.417	1.078	6.382	117.5	74.48	55.07	41.21	121.27	26.96	0.222	0.111	0.196
05PD026	12	2	N/A	N/A	N/A	N/A	0.46	0.36	0.78	0.07	2.31	0.4	0.14	0.05	0	0.46	0.21	0.46	0.02	-0.13
05QA001	60	2	49.76	36.78	29.52	23.42	48.78	14.7	0.3	-0.39	3.1	49.76	36.78	29.52	23.42	48.78	8.29	0.17	-0.08	0.16
05QA002	70	2	20.79	14.62	11.39	8.817	21.15	7.16	0.34	0.04	3.4	21.22	14.86	11.58	9.01	21.15	4.02	0.19	0.01	0.17
05QC001	29	2	8.154	4.218	2.561	1.44	8.82	6.45	0.73	1.6	7.38	7.5	3.27	1.83	0.99	8.82	3.35	0.38	0.19	0.25
05QD003	27	2	6.748	2.815	1.244	0.222	9.12	13.28	1.46	4.27	23.78	4.3	0.8	0.22	0.02	9.12	4.86	0.53	0.49	0.47
05QD006	28	2	21.05	13.46	9.412	6.131	19.51	8.83	0.45	0.04	2.37	19.11	11.92	8.61	6.21	19.51	5.14	0.26	0.01	0.06
05QD016	21	2	2.261	0.518	0.405	0.385	4.96	4.5	0.91	2.08	8.65	3.65	1.36	0.75	0.46	4.96	2.24	0.45	0.4	0.29
05QE006	49	2	87.19	49.7	32.78	20.71	88.25	45.82	0.519	0.3	2.82	85.43	47.71	30.65	18.45	88.25	26.021	0.295	0.056	0.116
05QE007	35	2	N/A	N/A	N/A	N/A	150.86	78.84	0.52	0.7	5.13	144.5	80.1	51.6	31.68	150.86	43.42	0.29	0.06	0.17
05QE008	21	2	4.678	3.222	2.622	2.223	4.39	2.03	0.46	0.38	2.57	3.71	2.43	2.08	1.9	4.39	1.18	0.27	0.1	0
05QE009	31	2	3.013	1.802	1.316	0.998	3.03	1.57	0.52	0.43	2.76	2.71	1.6	1.21	0.97	3.03	0.9	0.3	0.1	0.09
05RC001	11	2	N/A	N/A	N/A	N/A	8.13	1.87	0.23	-0.35	2.75	8.26	6.58	5.64	4.85	8.13	1.09	0.13	-0.11	-0.06

SUMMARY OF LOW FLOW FREQUENCY ANALYSIS
NORTHEASTERN REGION

Station	# of	Region	CONVENTIONAL MOMENTS (-1986)				L-MOMENTS (-1990)													
Number	Years	Code	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	Q	dQ	CV	CS	CK	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda 1	lambda 2	L-CV	L-CS	L-CK
02BF001	24	3	3.696	2.588	2.037	1.612	3.78	1.94	0.52	2	10.06	3.3	2.17	1.83	1.64	3.78	0.98	0.26	0.19	0.18
02BF002	24	3	2.768	1.798	1289	0.88	2.86	1.79	0.63	2.29	11.34	2.45	1.41	1.09	0.91	2.86	0.88	0.31	0.26	0.25
02BF004	12	3	N/A	N/A	N/A	N/A	0.07	0.07	1.02	2.92	13.31	0.04	0.23	0.02	0.02	0.07	0.03	0.44	0.58	0.51
02BF005	11	3	N/A	N/A	N/A	N/A	0.02	0.02	1.03	0.44	2.46	0.01	0.003	0	0	0.02	0.01	0.59	0.18	0.18
02BF006	12	3	N/A	N/A	N/A	N/A	0.02	0.03	1.35	1.77	7.5	0.01	0.002	0	0	0.02	0.01	0.7	0.46	0.16
02CA002	20	3	0.07	0.037	0.024	0.017	0.08	0.06	0.76	0.79	3.15	0.07	0.03	0.02	0.01	0.08	0.03	0.43	0.23	0.04
02CB003	11	3	N/A	N/A	N/A	N/A	3.18	1.04	0.33	0.61	4.63	3.1	2.29	1.94	1.69	3.18	0.57	0.18	0.21	0.28
02CC007	41	3	N/A	N/A	N/A	N/A	18.82	11.22	0.6	0.05	2.77	18.48	9.25	4.87	1.63	18.82	6.41	0.34	-0.05	0.05
02CC008	40	3	40.34	29.28	22.56	16.52	37.55	11.37	0.3	-0.67	3.44	38.88	28.83	22.72	17.23	37.55	6.34	0.17	-0.16	0.17
02CC009	31	3	N/A	N/A	N/A	N/A	33.04	16.96	0.51	1.16	8.42	31.43	17.55	11.51	7.32	33.04	8.64	0.26	-0.02	0.25
02CC010	11	3	N/A	N/A	N/A	N/A	4.08	1.2	0.29	-0.19	3.14	4.09	3.12	2.63	2.25	4.08	0.72	0.18	-0.06	0.03
02CD001	25	3	3.045	1.574	1.022	0.68	3.06	1.99	0.65	0.77	3.62	2.6	1.28	0.84	0.6	3.06	1.13	0.37	0.16	0.13
02CD002	14	3	0.129	0.033	0.005	0	0.12	0.16	1.37	1.8	7.09	0.06	0.011	0.002	0	0.12	0.08	0.69	0.49	0.2
02CD003	14	3	1.147	0.645	0.347	0.084	0.83	0.59	0.71	0.19	2.7	0.75	0.3	0.12	0.01	0.83	0.35	0.42	0.05	-0.00
02CD004	22	3	2.39	1.548	1.185	0.934	1.885	1.291	0.685	0.488	2.631	1.59	0.715	0.424	0.26	1.885	0.746	0.396	0.134	0.052
02CD006	23	3	0.719	0.498	0.4	0.331	0.652	0.291	0.446	0.512	2.943	0.609	0.396	0.313	0.261	0.652	0.168	0.258	0.133	0.09
02CE001	44	3	45.84	35.13	30.01	26.19	43.95	13.57	0.31	0.14	2.91	43.56	32.14	26.67	2.26	43.95	7.73	0.18	0.05	0.13
02CE002	76	3	4.004	3.185	2.833	2.591	4.08	1	0.25	0.62	3.22	3.99	3.19	2.84	2.6	4.08	0.56	0.14	0.13	0.13
02CF007	31	3	0.49	0.404	0.376	0.361	0.523	0.15	0.286	0.562	2.762	0.51	0.392	0.341	0.307	0.523	0.085	0.162	0.17	0.082
02CF010	15	3	1.778	1.288	1.138	1.058	1.84	0.8	0.44	0.98	4.95	1.71	1.15	0.95	0.82	1.84	0.45	0.24	0.19	0.14
02CF011	20	3	2.396	1.918	1.753	1.657	2.414	0.779	0.323	0.321	3.038	2.632	1.739	1.46	1.263	2.414	0.448	0.186	0.101	0.116
02CF012	14	3	N/A	N/A	N/A	N/A	0.76	0.21	0.28	-0.69	4.38	0.79	0.61	0.49	0.39	0.76	0.12	0.16	-0.12	0.24
02CF013	10	3	N/A	N/A	N/A	N/A	0.04	0.03	0.96	1.11	4.34	0.03	0.01	0.001	0	0.04	0.02	0.53	0.36	0.15
02DB007	11	3	N/A	N/A	N/A	N/A	0.13	0.07	0.53	-0.46	3.38	0.14	0.08	0.04	0.01	0.13	0.04	0.31	-0.13	0.1
02DC003	70	3	30.41	20.33	15.6	12.11	30.32	12.38	0.41	0.07	2.15	29.49	19.53	15.1	11.97	30.32	7.18	0.24	0.02	0.04
02DC008	52	3	0.503	0.06	0.014	0.003	1.73	3.43	1.98	2.12	6.52	0.51	0.06	0.01	0.003	1.73	1.43	0.83	0.67	0.34
02DD005	47	3	2.15	1.291	0.961	0.753	2.33	1.15	0.5	0.38	2.87	2.15	1.29	0.96	0.75	2.33	0.66	0.28	0.06	0.08
02DD008	27	3	0.121	0.075	0.053	0.036	0.12	0.06	0.46	-0.16	2.46	0.13	0.08	0.05	0.03	0.12	0.03	0.26	-0.04	0.02
02DD009	35	3	1.677	1.099	0.808	0.582	1.57	0.68	0.43	0.2	2.71	1.54	0.99	0.73	0.54	1.57	0.39	0.25	0.05	0.09
02DD010	30	3	43.15	31.04	27.18	25.05	47.06	18.48	0.39	0.89	3.29	42.89	31.24	27.46	25.36	47.06	10.36	0.22	0.23	0.1
02DD013	17	3	0.062	0.047	0.042	0.04	0.06	0.03	0.51	0.42	4.36	0.06	0.03	0.02	0.01	0.06	0.02	0.29	0.05	0.23
02DD015	17	3	0.136	0.078	0.06	0.051	0.19	0.22	1.16	3.19	15.24	0.11	0.05	0.042	0.039	0.19	0.09	0.49	0.51	0.41
02EA005	76	3	0.749	0.479	0.39	0.34	0.8	0.43	0.54	1.23	4.79	0.69	0.43	0.35	0.31	0.8	0.23	0.29	0.23	0.14
02EA006	76	3	1.95	1.196	0.85	0.6	1.97	0.97	0.49	0.54	4.15	1.89	1.09	0.74	0.5	1.97	0.54	0.27	0.06	0.18
02EA010	23	3	0.4	0.299	0.27	0.255	0.41	0.19	0.47	1.07	3.59	0.36	0.25	0.21	0.19	0.41	0.1	0.26	0.29	0.14
02EA011	18	3	N/A	N/A	N/A	N/A	6.312	4.438	0.703	1.558	5.592	5.125	2.658	1.946	1.583	6.312	2.318	0.367	0.36	0.237
02EA013	11	3	0.014	0.002	0	0	0.03	0.04	1.47	1.57	5.4	0.01	0.002	0	0	0.03	0.02	0.74	0.51	0.16
02JC008	23	3	3.808	2.964	2.622	2.398	3.94	1.1	0.28	0.44	3.81	3.82	2.97	2.61	2.38	3.94	0.62	0.16	0.06	0.2
02JD010	19	3	N/A	N/A	N/A	N/A	14.51	7.46	0.51	-0.59	2.84	14.63	8.05	4.66	1.98	14.51	4.29	0.3	-0.16	0.07
02JE012	9	3	N/A	N/A	N/A	N/A	35.74	82.6	0.231	0.037	3.072	356.5	286.2	251.5	225.1	357.4	47.32	0.132	-0.007	0.122
02JE018	12	3	0.37	0.11	0.003	0	0.05	0.05	0.88	1.27	4.88	0.04	0.01	0.003	0	0.05	0.03	0.48	0.35	0.19

TABLE B.1(b)

SUMMARY OF LOW FLOW FREQUENCY ANALYSIS

NORTHEASTERN REGION

Station Number	# of Years	Region Code	CONVENTIONAL MOMENTS (-1986)				L-MOMENTS (-1990)													
			$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	Q	dQ	CV	CS	CK	$7Q_2$	$7Q_5$	$7Q_{10}$	$7Q_{20}$	lambda 1	lambda 2	L-CV	L-CS	L-CK
02JE019	19	3	3.742	2.455	2.03	1.791	3.99	1.82		1.22	4.57	3.64	2.46	2.05	1.82	3.99	0.97	0.24	0.32	0.98
02JE020	20	3	1.527	1.021	0.907	0.859	1.95	1.34	0.69	1.56	5.6	1.09	1.01	0.92	0.88	1.95	0.68	0.35	0.42	0.16
04KA001	21	3	1.181	0.641	0.483	0.401	1.45	1.13	0.78	1.87	6.61	1.09	0.59	0.47	0.41	1.45	0.56	0.39	0.42	0.27
04LA002	22	1	N/A	N/A	N/A	N/A	27.67	7.72	0.28	0.3	2.59	25.91	20.57	18.77	17.73	27.67	4.5	0.16	0.08	0.01
04LF001	73	1	12	7.884	5.75	4.057	12.17	4.36	0.36	0.03	3.9	12.15	8.31	6.37	4.85	12.17	2.41	0.2	-0.02	0.19
04LG002	24	1	163.9	127.7	10.93	95.04	164.98	42.42	0.26	-0.13	2.06	166.1	129.9	111	95.99	164.98	24.66	0.15	-0.02	0.06
04LJ001	71	1	11.14	7.603	5.947	4.734	11.31	4.1	0.36	0.16	3.33	11.15	7.7	6.07	4.86	11.31	2.31	0.2	0.01	0.16
04LM001	19	1	21.4	16.37	14.24	12.78	22.95	6.49	0.28	0.4	3.49	22.45	17.3	15.03	13.45	22.95	3.74	0.16	0.09	0.16
04MD004	14	1	0.502	0.355	0.292	0.25	0.58	0.19	0.34	-0.14	2.97	0.58	0.42	0.34	0.29	0.58	0.12	0.2	-0.04	0.07
04ME002	59	1	143.7	120.7	107.8	96.88	142.71	215.22	0.18	-0.44	3.91	144.3	121.6	108.9	98.1	142.71	14.01	0.09	0.07	0.18
04ME003	32	1	N/A	N/A	N/A	N/A	174.78	30.76	0.18	0.41	3.11	172	147.7	137.3	130.1	174.78	17.62	0.1	0.08	0.126
04MF001	25	1	6.832	4.549	3.761	3.302	9.12	8.65	0.95	4.02	21.4	6.03	3.44	2.97	2.81	9.12	3.18	0.35	0.55	0.54

TABLE B.2(a)
SUMMARY OF 1, 3, 7, 15 & 30 DAY LOW FLOW
NORTHWESTERN REGION

STATION	1 DAY					3 DAY					7 DAY					15 DAY					30 DAY				
NO	2	5	10	20	100	2	5	10	20	100	2	5	10	20	100	2	5	10	20	100	2	5	10	20	100
02AA001	1.990	1.230	0.870	0.610	0.200	2.030	1.260	0.890	0.620	0.210	2.070	1.270	0.900	0.620	0.210	2.180	1.360	0.970	0.680	0.240	2.370	1.490	1.070	0.760	0.280
02AB006	18.160	12.070	9.480	7.710	5.360	21.200	14.600	11.960	9.960	7.150	24.590	17.760	14.680	12.480	9.320	26.880	19.930	16.710	14.370	10.910	29.590	22.090	18.280	15.310	10.420
02AB009	4.190	2.680	2.130	1.790	1.400	4.430	2.690	2.320	1.970	1.570	4.490	3.070	2.620	2.370	2.130	4.860	3.330	2.820	2.520	2.220	5.690	3.970	3.320	2.920	2.440
02AB010	13.710	8.330	5.700	3.710	0.570	17.650	12.030	9.550	7.810	5.390	21.120	15.230	12.710	10.980	8.660	23.920	17.700	14.830	12.750	9.680	26.300	19.530	18.180	13.810	9.530
02AB014	0.060	0.030	0.020	0.010	0.000	0.070	0.030	0.010	0.003	0.000	0.080	0.030	0.020	0.004	0.000	0.084	0.044	0.027	0.014	0.000	0.104	0.058	0.035	0.018	0.000
02AB015	0.500	0.340	0.290	0.260	0.240	0.530	0.350	0.290	0.250	0.200	0.530	0.350	0.290	0.250	0.204	0.560	0.380	0.310	0.280	0.230	0.570	0.400	0.340	0.320	0.290
02AB018	0.050	0.018	0.005	0.000	0.000	0.053	0.017	0.006	0.000	0.000	0.060	0.020	0.010	0.000	0.000	0.072	0.027	0.010	0.000	0.000	0.088	0.036	0.018	0.007	0.000
02AC001	0.650	0.430	0.330	0.260	0.150	0.857	0.431	0.331	0.262	0.185	0.670	0.430	0.330	0.260	0.179	0.681	0.448	0.362	0.310	0.251	0.738	0.520	0.447	0.406	0.365
02AD010	0.843	0.658	0.569	0.503	0.402	0.861	0.674	0.580	0.507	0.391	0.880	0.690	0.590	0.510	0.396	0.903	0.707	0.614	0.544	0.437	0.946	0.739	0.639	0.565	0.452
02AE001	0.790	0.470	0.360	0.300	0.230	0.790	0.470	0.360	0.300	0.230	0.810	0.480	0.370	0.310	0.243	0.850	0.510	0.390	0.320	0.250	0.690	0.540	0.420	0.360	0.300
02BA002	2.510	1.970	1.770	1.660	1.530	2.520	1.970	1.780	1.670	1.540	2.540	2.003	1.820	1.710	1.601	2.590	2.040	1.650	1.740	1.610	2.680	2.120	1.930	1.820	1.690
02BB002	3.900	2.510	1.790	1.220	0.270	3.910	2.500	1.780	1.220	0.280	3.930	2.490	1.780	1.220	0.370	4.000	2.480	1.760	1.210	0.370	4.120	2.470	1.730	1.210	0.460
02BB003	6.900	4.990	4.160	3.580	2.780	6.910	5.320	4.790	4.420	4.060	7.120	5.500	4.900	4.520	4.069	7.380	5.690	5.020	4.570	4.070	7.730	5.880	5.140	4.670	4.070
04CA002	94.580	63.320	51.470	44.060	35.320	94.910	63.330	51.420	44.010	35.320	95.440	63.480	51.480	44.030	35.780	96.520	63.960	51.790	44.260	35.510	99.010	65.720	53.090	45.200	35.890
04CA003	0.590	0.380	0.280	0.210	0.100	0.600	0.390	0.290	0.220	0.110	0.620	0.400	0.300	0.230	0.128	0.680	0.430	0.330	0.260	0.150	0.710	0.490	0.390	0.320	0.220
04CB001	42.370	33.740	29.680	27.160	23.300	42.640	33.690	29.950	27.150	23.150	42.930	34.060	30.060	27.200	23.870	43.460	34.620	30.310	27.360	23.120	44.560	35.230	30.650	27.640	22.640
04CC001	164.300	129.800	114.800	104.400	90.240	184.500	129.900	115.000	104.600	90.320	165.200	130.600	115.500	104.900	90.380	166.600	132.100	116.900	106.200	91.250	170.900	136.500	120.900	109.700	93.620
04CD002	12.260	10.350	10.020	9.910	9.850	12.470	10.500	10.160	10.040	9.970	12.600	10.610	10.270	10.150	10.080	12.700	10.700	10.380	10.270	10.210	13.070	11.020	10.690	10.590	10.530
04CE002	23.270	19.640	17.680	18.540	14.470	23.420	19.770	17.960	16.590	14.410	23.620	19.920	18.070	16.650	14.370	23.800	20.090	18.220	16.780	14.450	24.090	20.360	18.470	17.000	14.600
04DA001	8.680	8.640	5.930	5.540	5.160	8.920	8.860	5.940	5.550	5.160	6.980	6.720	6.020	5.640	5.430	9.080	6.820	6.140	5.790	5.470	9.360	7.400	8.690	6.250	5.750
04DC001	86.810	64.990	60.270	58.300	57.000	86.480	64.870	60.200	58.290	57.030	88.230	64.690	60.450	58.670	57.050	65.900	65.560	81.690	60.230	59.380	85.970	69.290	66.740	65.930	65.540
04DC002	2.590	1.740	1.370	1.120	0.770	2.600	1.750	1.380	1.130	0.770	2.620	1.770	1.400	1.130	0.770	2.670	1.610	1.420	1.150	0.760	2.750	1.880	1.470	1.180	0.900
04FA001	15.940	12.150	10.680	9.760	8.650	15.980	12.150	10.880	9.760	8.660	16.050	12.140	10.670	9.750	8.831	16.240	12.190	10.700	9.790	8.760	16.700	12.440	10.910	9.990	8.970
04FA002	2.960	2.410	2.170	2.010	1.800	2.980	2.420	2.180	2.020	1.800	3.000	2.430	2.190	2.020	1.803	3.050	2.470	2.220	2.050	1.610	3.170	2.550	2.280	2.090	1.830
04FB001	48.440	31.110	24.690	20.740	18.190	48.490	31.050	24.830	20.710	18.240	48.930	38.320	32.230	20.990	18.340	49.170	30.940	24.530	20.750	18.640	50.540	31.330	24.960	21.350	17.870
04FC001	54.970	47.480	45.030	43.870	42.300	55.040	47.490	45.040	43.670	42.300	55.270	47.640	45.150	43.770	42.380	58.080	48.190	45.520	43.990	42.390	57.290	49.480	48.970	45.570	44.200
04GA002	17.310	11.440	9.830	9.040	8.390	17.380	11.460	9.650	9.060	8.410	17.450	11.540	9.920	9.125	6.460	17.650	11.870	10.050	9.250	8.590	18.130	11.980	10.290	9.460	8.760
04GB004	42.530	35.290	30.540	26.020	15.910	42.620	35.360	30.810	26.080	15.950	42.640	35.440	30.650	26.130	16.180	42.670	35.330	30.790	26.750	18.620	43.570	35.720	31.090	27.020	19.020
04GC002	17.770	11.740	9.160	7.390	5.000	17.860	11.810	9.210	7.410	4.980	17.860	11.910	9.220	7.210	4.824	18.450	12.260	9.490	7.540	4.770	19.190	12.600	9.680	7.760	4.680
04GD001	58.450	40.810	34.270	30.260	25.850	58.530	40.800	34.310	30.360	25.870	58.730	40.800	34.380	30.550	26.320	59.430	41.070	34.750	31.070	27.160	60.370	41.130	35.030	31.700	28.460
04JA002	10.200	7.740	6.660	5.910	4.870	10.270	7.780	6.890	5.920	4.860	10.370	7.830	6.710	5.920	4.830	10.690	8.090	6.890	6.020	4.730	11.190	8.430	7.130	8.170	4.730
04JC002	4.340	3.040	2.380	1.680	0.990	4.350	3.100	2.480	2.010	1.250	4.410	3.180	2.590	2.150	1.481	4.540	3.290	2.700	2.260	1.590	4.770	3.430	2.600	2.350	1.680
04JF001	12.140	8.580	7.420	6.770	6.120	12.150	8.580	7.430	6.780	6.140	12.180	8.590	7.440	6.800	6.235	12.300	8.610	7.450	6.820	8.240	12.580	8.680	7.500	6.870	8.290
05PA012	9.960	8.500	4.870	3.670	1.860	10.020	8.540	4.910	3.700	1.680	10.150	6.630	4.980	3.770	1.961	10.400	6.760	5.090	3.870	2.090	10.810	7.000	5.260	4.010	2.190
05PB009	3.830	1.070	0.410	0.110	0.000	5.920	1.680	0.620	0.140	0.000	10.390	3.730	1.620	0.470	0.000	12.360	5.010	2.950	1.910	1.030	17.750	9.400	8.250	4.270	1.950
05PC018	113.200	78.520	62.730	51.390	34.960	126.900	91.240	74.690	62.630	44.810	144.000	104.500	85.990	72.340	51.830	152.200	112.200	95.300	63.880	66.730	160.100	119.200	103.300	93.160	80.940
05PC019	60.370	28.700	17.520	11.000	3.880	90.870	53.940	38.720	28.580	15.480	117.500	74.480	55.070	41.210	21.360	129.100	63.650	62.700	47.500	25.200	139.200	92.090	70.310	54.490	31.200
05PD026	0.310	0.110	0.040	0.000	0.000	0.340	0.130	0.040	0.000	0.000	0.400	0.140	0.050	0.000	0.000	0.520	0.200	0.070	0.000	0.000	0.640	0.240	0.090	0.000	0.000
05QA001	48.730	35.040	28.330	23.260	15.320	48.900	35.060	28.340	23.270	15.370	49.760	36.780	29.510	23.420	15.410	49.700	35.490	28.640	23.490	15.530	50.780	36.190	29.130	23.810	15.560
05QC001	8.730	2.750	1.490	0.800	0.120	7.010	2.950	1.810	0.870	0.120	7.500	3.270	1.830	0.990	0.190	7.900	3.560	2.060	1.180	0.230	6.970	4.520	2.880	1.870	0.710
05QD003	3.490	1.260	0.550	0.150	0.000	3.690	0.670	0.180	0.020	0.000	4.300	0.800	0.220	0.020	0.000	4.770	0.940	0.270	0.030	0.000	5.460	2.350	1.870	1.720	1.640
05QD006	15.030	8.500	8.020	4.470	2.650	16.350	9.570	6.820	5.000	2.670	19.110	11.920	8.610	6.210	2.688	21.940	14.540	10.480	7.120	1.060	23.580	15.880	11.210	7.130	1.180
05QD018	2.550	0.850	0.200	0.010	0.000	3.230	1.110	0.540	0.270	0.050	3.650	1.360	0.750	0.460	0.218	4.150	1.770	1.120	0.790	0.530	4.440	2.140	1.540	1.250	1.030
05QE006	70.400	37.090	22.930	13.270	0.350	78.800	43.160	27.410	16.340	0.850	65.430	47.710	30.650	18.450	0.921	89.970	51.200	33.880	21.610	4.240	97.060	58.910	38.230	24.580	4.320
05QE007	28.440	7.970	3.060	0.870	0.000	84.370	39.680	22.200	11.010	0.000	144.500	80.100	51.600	31.680	3.790	165.300	96.000	63.660	40.450	5.660	185.500	111.700	76.610	50.490	10.660
05QE008	3.660	2.410	2.060	1.890	1.740	3.690	2.430	2.070	1.900	1.740	3.710	2.430	2.080	1.900	1.778	4.080	2.640	2.130	1.830	1.490	4.150	2.680	2.160	1.850	1.500
05QE009	2.610	1.530	1.160	0.950	0.720	2.640	1.550	1.170	0.960	0.720	2.720	1.600	1.210	0.970	0.720	2.800	1.660	1.240	0.990	0.720	2.930	1.730	1.290	1.020	0.720

TABLE B.2(b)
SUMMARY OF 1, 3, 7, 15 & 30 DAY LOW FLOW
NORTHEASTERN REGION

STATION	1 DAY					3 DAY					7 DAY					15 DAY					30 DAY				
NO.	2	5	10	20	100	2	5	10	20	100	2	5	10	20	100	2	5	10	20	100	2	5	10	20	100
02BF001	3.150	2.090	1.740	1.550	1.350	3.200	2.090	1.740	1.560	1.390	3.300	2.170	1.830	1.640	1.470	3.570	2.350	1.960	1.750	1.540	4.010	2.660	2.190	1.920	1.630
02BF002	2.220	1.280	1.000	0.850	0.700	2.300	1.330	1.030	0.870	0.720	2.450	1.410	1.090	0.910	0.744	2.770	1.600	1.220	1.010	0.800	3.130	1.830	1.410	1.170	0.930
02BF004	0.036	0.022	0.020	0.019	0.019	0.038	0.023	0.020	0.019	0.019	0.040	0.023	0.022	0.020	0.018	0.054	0.026	0.021	0.018	0.017	0.078	0.040	0.031	0.028	0.025
02BF006	0.0081	0.0013	0.0001	0.000	0.000	0.0097	0.0016	0.0001	0.000	0.000	0.010	0.002	0.000	0.000	0.000	0.0143	0.0025	0.0022	0.000	0.000	0.0146	0.0019	0.0001	0.000	0.000
02CA002	0.045	0.023	0.015	0.011	0.060	0.050	0.024	0.016	0.011	0.006	0.070	0.030	0.020	0.011	0.0049	0.093	0.037	0.020	0.011	0.003	0.138	0.058	0.034	0.021	0.010
02CC007	5.150	1.320	0.920	0.250	0.000	7.780	2.640	1.180	0.430	0.000	18.480	9.250	4.870	1.630	0.000	24.350	14.130	8.490	3.790	0.000	29.440	18.330	12.410	7.680	0.000
02CC008	25.150	14.690	10.200	7.110	2.920	33.440	22.850	17.080	12.330	3.860	38.880	28.830	22.720	17.230	6.020	40.970	30.650	24.800	19.820	10.510	43.560	32.500	27.090	22.970	16.490
02CC009	15.260	8.410	2.980	1.620	0.230	19.970	8.230	4.330	2.130	0.540	31.430	17.550	11.510	7.320	1.560	35.680	21.890	15.970	11.900	8.380	40.350	28.930	21.420	17.750	13.030
02CC010	4.020	3.040	2.510	2.070	1.280	4.060	3.070	2.540	2.110	1.340	4.090	3.120	2.630	2.250	1.631	4.160	3.170	2.710	2.370	1.850	4.290	3.210	2.770	2.470	2.100
02CD001	2.487	1.207	0.779	0.5370	0.287	2.527	1.232	0.802	0.558	0.308	2.600	1.280	0.840	0.600	0.348	2.764	1.392	0.932	0.670	0.400	3.016	1.533	1.035	0.750	0.454
02CD002	0.037	0.005	0.0006	0.000	0.000	0.045	0.007	0.0009	0.000	0.000	0.060	0.011	0.002	0.000	0.000	0.072	0.013	0.002	0.000	0.000	0.087	0.017	0.003	0.000	0.000
02CD004	1.510	0.640	0.380	0.230	0.100	1.560	0.670	0.390	0.240	0.100	1.590	0.715	0.424	0.260	0.091	1.790	0.790	0.460	0.280	0.100	1.970	0.860	0.500	0.310	0.110
02CD006	0.573	0.339	0.230	0.151	0.035	0.598	0.358	0.245	0.181	0.038	0.609	3.960	0.313	0.261	0.198	0.693	0.484	0.404	0.355	0.296	0.818	0.564	0.460	0.392	0.305
02CE001	20.950	11.350	7.780	5.580	3.050	35.180	24.500	19.290	15.340	9.160	43.560	32.140	28.670	22.600	18.120	47.770	38.130	30.380	25.990	19.010	15.820	39.420	32.980	27.840	19.170
02CE002	3.830	3.050	2.720	2.500	2.210	3.890	3.100	2.770	2.540	2.230	3.990	3.190	2.840	2.600	2.278	4.140	3.310	2.950	2.700	2.360	4.420	3.500	3.100	2.830	2.470
02CF007	0.460	0.350	0.300	0.270	0.230	0.480	0.370	0.320	0.290	0.250	0.510	0.392	0.341	0.307	0.260	0.540	0.410	0.350	0.310	0.260	0.590	0.430	0.370	0.320	0.270
02CF010	1.600	1.070	0.870	0.740	0.600	1.640	1.100	0.890	0.780	0.610	1.710	1.150	0.980	0.820	0.681	1.820	1.250	1.040	0.920	0.780	2.090	1.430	1.170	1.000	0.800
02CF012	0.640	0.490	0.410	0.350	0.260	0.710	0.540	0.450	0.370	0.240	0.790	0.810	0.490	0.390	0.169	0.910	0.690	0.560	0.440	0.190	1.070	0.840	0.680	0.520	0.150
02DB007	0.105	0.053	0.030	0.014	0.000	0.114	0.058	0.033	0.014	0.000	0.140	0.060	0.040	0.010	0.000	0.170	0.062	0.038	0.017	0.001	0.190	0.071	0.043	0.021	0.009
02DC003	18.340	9.180	5.260	2.590	0.000	25.820	16.190	11.790	8.630	4.050	29.490	19.530	15.100	11.970	7.573	32.020	21.650	18.940	13.570	8.690	34.500	23.730	18.690	14.980	9.440
02DC008	0.060	0.004	0.0006	0.0001	0.000	0.170	0.020	0.003	0.0006	0.000	0.510	0.060	0.010	0.003	0.000	1.740	0.360	0.120	0.030	0.000	5.780	2.180	1.060	0.460	0.000
02DD005	1.095	0.893	0.592	0.546	0.511	1.578	0.925	0.735	0.637	0.549	2.150	1.290	0.960	0.750	0.570	2.690	1.731	1.391	1.188	0.966	3.403	2.297	1.884	1.628	1.333
02DD009	1.027	0.506	0.302	0.171	0.011	1.336	0.765	0.495	0.296	0.000	1.540	0.990	0.730	0.540	0.341	1.657	1.102	0.864	0.702	0.484	1.762	1.257	1.072	0.959	0.830
02DD010	42.030	30.570	28.820	24.710	22.590	42.310	30.820	27.070	24.970	22.870	42.890	31.240	27.460	25.360	23.260	44.400	32.220	28.240	28.020	23.780	47.740	33.690	29.070	28.470	23.640
02DD013	0.046	0.024	0.018	0.011	0.004	0.050	0.028	0.019	0.014	0.004	0.060	0.030	0.020	0.014	0.0047	0.062	0.035	0.025	0.020	0.015	0.082	0.051	0.038	0.030	0.020
02EA005	0.667	0.383	0.283	0.225	0.162	0.651	0.397	0.323	0.284	0.249	0.690	0.430	0.350	0.310	0.268	0.778	0.493	3.950	0.338	0.279	0.883	0.574	0.467	0.405	0.339
02EA006	1.592	0.851	0.549	0.350	0.095	1.692	0.833	0.813	0.396	0.108	1.890	1.090	0.740	0.540	0.324	2.165	1.345	0.972	0.704	0.327	2.559	1.699	1.305	1.020	0.607
02EA010	0.310	0.205	0.172	1.540	0.137	0.324	0.226	0.197	0.183	0.170	0.360	0.250	0.210	0.190	0.177	0.406	0.280	0.245	0.228	0.213	0.479	0.329	0.264	0.261	0.239
02EA011	4.798	2.513	1.866	1.541	1.260	4.920	2.573	1.902	1.562	1.264	5.125	2.658	1.946	1.583	1.264	5.564	2.834	2.022	1.598	1.213	8.320	3.123	2.173	1.678	1.228
02EA013	0.011	0.0015	0.000	0.000	0.000	0.012	0.0018	0.000	0.000	0.000	0.013	0.002	0.000	0.000	0.000	0.019	0.003	0.000	0.000	0.000	0.042	0.008	0.0004	0.000	0.000
02JC008	3.660	2.779	2.393	2.123	1.748	3.720	2.854	2.480	2.221	1.868	3.820	2.970	2.610	2.380	2.062	4.055	3.229	2.890	2.666	2.377	4.609	3.639	3.180	2.840	2.327
02JD010	0.880	0.620	0.052	0.000	0.000	1.730	0.349	0.088	0.000	0.000	14.630	8.050	4.660	1.980	0.000	20.710	13.370	9.397	8.142	0.382	25.850	17.910	13.390	9.518	2.215
02JE012	149.500	63.870	32.580	13.800	0.000	284.600	199.800	145.700	95.730	0.000	356.500	286.200	251.500	225.100	182.900	373.000	305.400	272.600	247.900	209.500	397.000	324.000	287.000	260.000	215.800
02JE018	0.0214	0.0043	0.0006	0.000	0.000	0.033	0.009	0.002	0.000	0.000	0.040	0.010	0.003	0.000	0.000	0.057	0.031	0.023	0.018	0.014	0.080	0.050	0.040	0.034	0.030
02JE019	3.429	2.309	1.934	1.720	1.499	3.501	2.366	1.981	1.760	1.529	3.640	2.460	2.050	1.820	1.569	3.947	2.708	2.275	2.020	1.746	4.292	2.913	2.435	2.156	1.857
02JE020	1.206	0.806	0.734	0.708	0.693	1.257	0.835	0.757	0.728	0.711	1.490	1.010	0.920	0.880	0.854	2.412	1.474	1.187	1.034	0.890	3.569	2.385	1.834	1.431	0.833
04KA001	1.090	0.589	0.463	0.404	0.359	1.090	0.592	0.469	0.413	0.372	1.090	0.592	0.470	0.413	0.373	1.102	0.594	0.480	0.431	0.398	1.123	0.593	0.483	0.440	0.412
04LA002	23.210	17.380	15.220	13.890	12.360	24.430	18.980	17.050	15.920	14.650	25.910	20.570	18.770	17.330	16.650	28.850	22.680	20.180	18.540	16.650	30.660	24.020	21.200	19.300	16.760
04LF001	5.007	1.802	0.869	0.392	0.000	10.370	8.178	4.101	2.509	0.000	12.150	8.310	6.370	4.850	2.380	12.930	9.142	7.229	5.739	3.304	13.840	9.957	7.978	6.428	3.870
04LG002	128.900	86.610	67.470	53.780	34.080	153.200	113.200	93.660	77.890	51.850	166.100	129.900	111.000	95.990	80.280	174.300	136.400	118.300	100.100	92.090	181.200	144.800	128.500	118.900	100.300
04LJ001	10.780	7.310	5.668	4.452	2.612	10.890	7.440	5.817	4.622	2.828	11.150	7.700	6.070	4.860	3.039	11.540	8.023	6.357	5.124	3.257	12.290	8.609	6.865	5.573	3.618
04LM001	22.150	17.080	14.860	13.310	11.160	22.280	17.170	14.930	13.350	11.180	22.450	17.300	15.030	13.450	11.240	23.010	17.710	15.350	13.690	11.340	23.860	18.190	15.750	14.070	11.790
04MD004	0.537	0.349	0.249	0.168	0.029	0.550	0.377	0.290	0.222	0.113	0.580	0.420	0.340	0.290	0.235	0.620	0.470	0.395	0.338	0.245	0.708	0.549	0.459	0.382	0.239
04ME002	79.710	57.160	45.820	37.030	22.760	112.500	89.940	77.860	68.060	50.950	144.300	121.600	108.900	98.100	78.140	155.700	133.000	120.500	110.100	91.170	164.500	141.700	130.000	120.800	105.700
04ME003	80.200	50.100	37.150	28.240	18.150	138.300	106.900	89.420	74.850	48.330	172.000	147.700	137.300	130.100	120.500	187.800	165.100	154.800	147.500	136.900	205.300	180.300	168.300	159.200	145.200
04MF001	8.110	3.501	2.995	2.802	2.688	6.079	3.483	2.993	2.810	2.704	6.030	3.440	2.970	2.800	2.815	5.951	3.393	2.978	2.839	2.769	5.792	3.365	3.050	2.961	2.924

FREQUENCY CURVE PARAMETERS (a, e, u)
NORTHWESTERN REGION

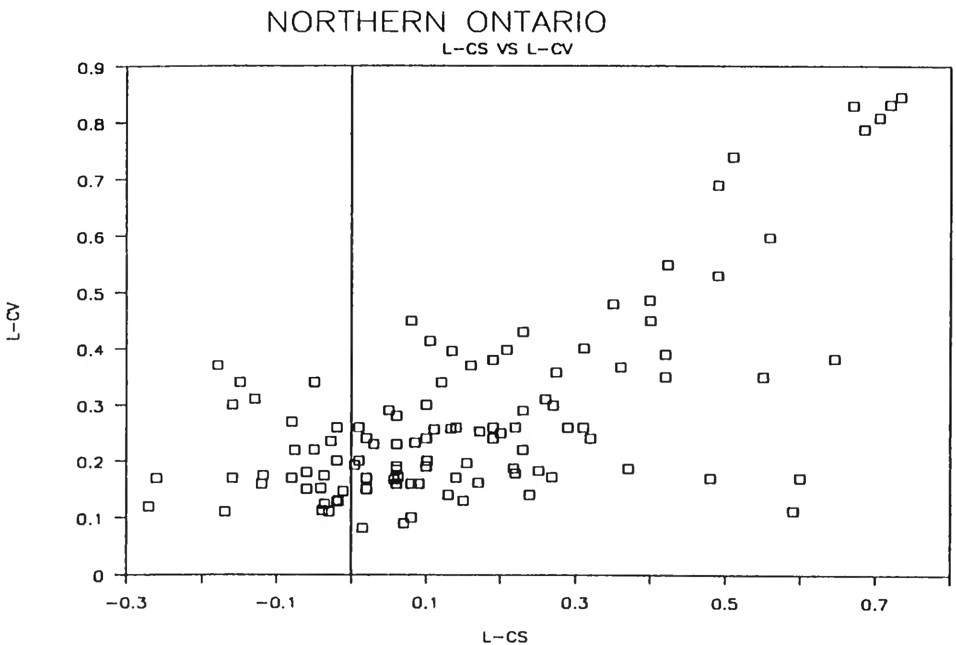
STATION NO.	1 DAY a	1 DAY e	1 DAY u	3 DAY a	3 DAY e	3 DAY u	7 DAY a	7 DAY e	7 DAY u	15 DAY a	15 DAY e	15 DAY u	30 DAY a	30 DAY e	30 DAY u
02AA001	2.860	−0.320	2.310	2.860	− 0.33	2.350	2.768	−0.311	2.412	2.860	−0.340	2.520	2.910	−0.350	2.730
02AB006	2.150	3.270	20.920	2.380	4.290	24.010	2.490	5.910	27.550	2.670	6.800	29.830	3.590	1.910	32.560
02AB009	1.640	1.160	4.950	1.640	1.330	5.210	1.310	2.040	5.280	1.420	2.080	5.680	1.710	2.140	6.540
02AB010	3.140	−4.0500	15.910	2.350	2.960	20.130	2.180	6.570	23.790	2.650	6.070	26.570	3.260	3.230	29.040
02AB014	2.010	−0.010	0.080	2.240	−0.030	0.082	2.363	−0.032	0.093	2.330	−0.020	0.100	3.140	−0.050	0.120
02AB015	1.230	0.230	0.590	1.640	0.170	0.620	1.493	0.184	0.611	1.220	0.280	0.670	1.540	0.210	0.660
02AB016	1.340	−0.010	0.070	1.380	−0.010	0.070	1.704	−0.017	0.073	1.680	−0.020	0.100	1.540	−0.010	0.110
02AC001	2.750	0.010	0.740	2.330	0.070	0.760	2.012	0.111	0.780	1.620	0.220	0.800	1.400	0.350	0.860
02AD010	2.940	0.260	0.920	3.370	0.200	0.940	3.575	0.168	0.958	2.920	0.290	0.980	2.920	0.300	1.030
02AE001	1.430	0.200	0.960	1.430	0.200	1.970	1.424	0.212	0.987	1.440	0.220	1.040	1.360	0.270	1.090
02BA002	1.530	1.470	2.800	1.520	1.480	2.800	1.463	1.546	2.819	1.510	1.550	2.880	1.490	1.630	2.970
02BB002	3.830	−1.530	4.440	3.690	−1.400	4.460	3.195	−0.105	4.452	2.980	−0.790	4.620	2.450	−0.340	4.830
02BB003	2.300	2.000	7.750	1.540	3.860	7.730	1.713	3.788	7.908	1.950	3.570	8.170	1.880	3.640	8.600
04CA002	1.720	29.800	109.960	1.700	29.900	110.500	1.894	23.272	113.450	1.680	30.200	112.700	1.720	29.990	115.400
04CA003	2.730	−0.030	0.680	2.730	−0.030	0.690	2.575	0.010	0.714	2.500	0.040	0.760	2.460	0.110	0.810
04CB001	2.420	19.290	46.100	2.470	18.890	46.440	3.670	14.590	47.090	2.530	18.430	47.400	2.740	16.940	48.600
04CC001	2.260	76.790	179.800	2.260	76.800	179.800	2.301	76.258	180.526	2.350	76.340	181.900	2.520	75.900	185.800
04CD002	0.720	9.840	13.860	0.730	9.970	14.100	0.728	10.080	14.243	0.700	10.210	14.400	0.680	10.530	14.900
04CE002	3.070	11.520	24.800	3.220	11.100	24.900	3.350	10.370	25.110	3.430	10.610	25.300	3.540	10.500	25.600
04DA001	1.310	5.000	10.130	1.320	5.000	10.200	2.024	3.260	10.860	1.210	5.360	10.400	1.630	5.460	10.350
04DC001	0.880	56.760	102.000	0.870	56.800	102.000	0.826	62.500	102.930	0.790	59.300	101.700	0.670	65.500	100.800
04DC002	2.270	0.430	2.970	2.890	0.430	2.980	2.360	0.395	2.999	2.460	0.340	3.040	2.640	0.240	3.120
04FA001	1.770	7.910	17.790	1.750	7.940	17.860	2.022	7.748	18.280	1.630	8.160	18.280	1.580	8.400	18.870
04FA002	2.150	1.610	3.220	2.150	1.610	3.230	2.144	1.611	3.258	2.200	1.600	3.320	2.360	1.560	3.440
04FB001	1.660	13.480	57.100	1.630	13.620	57.300	1.033	28.940	54.693	1.520	14.500	58.600	1.390	16.000	60.900
04FC001	1.360	41.710	59.060	1.360	41.720	59.180	1.360	41.780	59.450	1.440	41.640	60.280	1.340	43.620	61.590
04GA002	1.090	8.190	20.920	1.100	8.210	20.990	2.519	−5.825	16.535	1.090	8.400	21.350	1.100	8.560	21.910
04GB004	93.610	−559.400	44.890	95.430	−571.980	44.990	42.590	−238.690	45.270	9.870	−26.670	45.500	8.250	−17.590	46.350
04GC002	2.190	2.840	20.490	2.220	2.730	20.580	2.925	−0.005	19.900	2.420	1.900	21.160	2.600	1.140	21.930
04GD001	1.650	22.900	69.300	1.620	23.300	67.500	1.625	29.369	68.720	1.470	25.200	69.100	1.310	27.200	71.100
04JA002	2.310	3.860	11.290	2.320	3.820	11.370	2.338	3.747	11.496	2.650	3.210	11.800	2.780	2.930	12.350
04JC002	3.720	−0.590	4.850	3.260	0.080	4.860	2.938	0.573	4.920	2.870	0.720	5.060	2.660	0.890	5.340
04JF001	1.360	5.840	14.080	1.350	5.870	14.120	1.418	6.942	14.462	1.300	5.970	14.370	1.240	6.070	14.820
05PA012	2.790	−0.410	11.410	2.800	−0.430	11.480	2.745	−0.267	11.643	2.630	0.020	11.950	2.570	0.140	12.450
05PB009	0.990	−0.310	8.590	0.990	−0.320	8.690	1.422	−0.731	14.460	1.130	0.750	16.800	1.710	0.490	21.870
05PC018	2.550	16.640	128.100	2.680	23.600	142.100	2.780	26.050	160.530	2.110	55.700	170.500	1.790	72.700	179.900
05PC019	1.520	0.180	76.800	2.020	4.930	107.900	2.490	−0.096	136.180	2.630	−0.820	148.500	2.650	3.800	159.300
05PD026	1.720	−0.095	0.400	1.800	−0.110	0.440	1.109	0.201	0.488	2.010	−0.220	0.660	1.790	−0.210	0.840
05QA001	3.100	3.840	54.400	3.070	4.110	54.580	5.618	−21.273	54.550	3.000	4.480	55.570	3.040	3.950	56.790
05QC001	1.310	−0.150	8.940	1.370	−0.210	9.220	1.457	−0.319	9.736	1.490	−0.240	10.180	1.650	0.010	11.190
05QD003	1.320	−0.390	4.730	0.700	−0.070	6.270	0.709	−0.088	7.271	0.740	−0.110	7.890	0.680	1.680	8.190
05QD006	1.720	1.490	18.240	1.970	0.870	19.520	2.632	−1.422	22.175	5.040	−14.770	24.710	10.790	−53.560	26.240
05QD016	0.940	−0.160	3.850	1.070	−0.020	4.550	1.069	0.152	5.085	1.100	0.450	5.610	1.040	0.970	5.900
05QE006	2.160	−11.100	85.500	2.460	−14.700	94.500	2.505	−18.190	101.760	2.430	−13.900	106.900	2.700	−20.150	114.100
05QE007	0.960	−1.080	42.200	1.820	−12.100	105.900	2.360	−24.180	172.840	2.670	−35.400	194.800	2.890	−41.990	216.200

TABLE D.3(b)

FREQUENCY CURVE PARAMETERS (a, e, u)

NORTHEASTERN REGION

STATION	1 DAY			3 DAY			7 DAY			15 DAY			30 DAY		
NO.	a	e	u	a	e	u	a	e	u	a	e	u	a	e	u
02BF001	1.350	1.270	3.740	1.270	1.320	3.830	1.256	1.401	3.947	1.330	1.450	4.240	1.460	1.490	4.730
02BF002	1.240	0.650	2.760	1.260	0.660	2.850	1.290	0.677	3.032	1.350	0.720	3.410	1.360	0.830	3.840
02BF004	0.650	0.020	0.050	0.680	0.020	0.050	0.686	0.029	0.063	0.810	0.020	0.080	0.870	0.030	0.110
02BF006	0.740	−0.0006	0.010	0.760	−0.0008	0.020	1.022	−0.002	0.021	0.800	−0.0012	0.020	0.660	−0.001	0.030
02CA002	1.510	0.004	0.060	1.360	0.004	0.060	1.282	0.003	0.086	1.240	−0.0005	0.130	1.240	0.005	0.180
02CC007	1.130	−0.520	8.830	1.160	−0.430	10.840	2.841	−9.596	22.350	5.210	−27.900	28.200	4.280	−18.300	33.700
02CC008	2.210	−0.930	29.800	4.840	−17.300	37.400	11.220	−65.700	42.350	6.100	−19.910	44.740	3.160	6.870	48.060
02CC009	1.280	−1.100	20.400	1.390	−1.130	26.300	2.277	−3.956	37.610	10.300	71.200	40.610	4.620	−11.690	45.320
02CC010	4.920	−0.740	4.390	4.620	−0.470	4.430	3.522	0.574	4.477	2.830	1.180	4.570	1.990	1.790	4.790
02CD001	1.410	0.170	3.180	1.400	0.200	3.230	1.385	0.237	3.317	1.420	0.270	3.500	1.420	0.310	3.810
02CD002	0.660	−0.002	0.070	0.700	−0.002	0.080	0.766	−0.004	0.098	0.790	−0.005	0.120	0.820	−0.007	0.140
02CD004	1.270	0.040	2.000	1.280	0.040	2.070	1.423	0.014	2.057	1.340	0.020	2.350	1.340	0.030	2.580
02CD006	2.650	−0.100	0.670	2.800	−0.120	0.699	1.779	0.156	0.713	1.720	0.260	0.800	1.960	0.240	0.940
02CE001	1.660	1.530	25.700	3.110	0.170	39.500	2.740	11.259	48.060	3.240	8.320	52.500	3.940	2.240	56.650
02CE002	2.120	1.950	4.180	2.170	1.950	4.250	2.229	1.978	4.346	2.250	2.040	4.520	2.170	2.150	4.840
02CF007	2.180	0.190	0.510	2.160	0.210	0.530	2.188	0.218	0.563	2.150	0.220	0.600	1.930	0.230	0.660
02CF010	1.730	0.500	1.850	1.760	0.500	1.910	1.631	0.598	1.985	1.550	0.710	2.110	1.840	0.660	2.400
02CF012	3.270	0.110	0.700	4.540	−0.060	0.770	11.810	−1.199	0.850	14.210	−1.900	0.980	1.580	−0.680	0.440
02DB007	2.290	−0.030	0.130	2.650	−0.050	0.140	9.447	−0.380	0.157	2.720	−0.080	0.210	2.810	−0.100	0.260
02DC003	2.180	−4.260	22.490	2.560	−1.090	29.970	2.397	3.052	33.853	2.530	3.290	36.490	2.760	2.560	39.040
02DC008	0.410	0.000	0.140	0.480	−0.0002	0.370	0.546	−0.001	1.003	0.730	−0.020	2.890	0.270	−0.330	7.810
02DD005	1.000	0.500	1.360	1.180	0.520	1.960	1.758	0.343	2.568	1.540	0.850	3.180	1.670	1.150	3.950
02DD009	1.830	−0.090	1.280	2.810	−0.390	1.580	2.573	0.052	1.779	2.180	0.290	1.910	1.630	0.750	2.020
02DD010	1.370	21.700	48.300	1.360	21.960	48.590	1.350	22.370	49.290	1.370	22.810	51.040	1.380	22.700	55.400
02DD013	1.850	−0.0009	0.060	2.000	−0.0003	0.061	2.303	−0.005	0.068	1.430	0.011	0.077	1.850	0.010	0.098
02EA005	1.500	0.130	0.820	1.200	0.240	0.800	1.247	0.253	0.842	1.460	0.250	0.930	1.500	0.310	1.050
02EA006	1.970	−0.100	1.940	2.120	−0.140	2.040	2.203	0.057	2.214	2.540	−0.110	2.520	2.580	0.140	2.930
02EA010	1.280	0.130	0.370	1.160	0.170	0.380	1.259	0.170	0.426	1.130	0.210	0.480	1.220	0.230	0.560
02EA011	1.140	1.170	6.170	1.150	1.170	6.320	1.164	1.160	6.590	1.200	1.080	7.150	1.210	1.070	8.180
02EA013	0.590	−0.0001	0.019	0.690	−0.0009	0.021	0.720	−0.0011	0.024	0.730	−0.002	0.030	0.840	−0.005	0.070
02JC008	2.320	1.380	4.050	2.240	1.540	4.110	2.067	1.802	4.210	2.000	2.150	4.440	2.830	1.670	5.020
02JD010	0.760	−0.060	2.000	0.780	−0.080	2.810	3.789	−10.813	17.210	4.690	−13.470	23.690	6.370	−22.810	28.730
02JE012	1.590	−19.100	193.100	22.000	120.000	260.000	3.230	118.740	387.890	3.050	155.300	400.900	3.280	147.000	426.600
02JE018	0.850	−0.002	0.030	1.160	−0.006	0.050	1.389	−0.011	0.059	1.250	0.010	0.070	1.280	0.030	0.098
02JE019	1.410	1.390	4.030	1.440	1.420	4.110	1.469	1.446	4.255	1.500	1.610	4.590	1.490	1.710	5.010
02JE020	0.760	0.690	1.530	0.770	0.710	1.600	0.829	0.850	1.848	1.250	0.840	2.950	2.710	0.110	4.070
04KA001	1.010	0.350	1.420	0.980	0.360	1.420	0.961	0.364	1.431	0.900	0.390	1.460	0.840	0.410	1.520
04LA002	1.660	11.450	26.120	1.530	14.030	27.250	1.435	16.140	28.760	1.950	14.850	31.740	2.120	14.570	33.710
04LF001	1.180	−0.170	6.900	3.280	−3.980	12.070	3.524	−1.824	13.687	3.530	−0.840	14.430	3.640	−0.660	15.370
04LG002	2.510	12.500	147.100	3.640	5.680	168.800	4.145	31.503	179.500	4.270	11.800	188.900	2.470	82.600	196.900
04LJ001	2.840	0.240	12.240	2.780	0.580	12.350	2.829	0.699	12.597	2.840	0.850	13.020	2.840	1.090	13.840
04LM001	2.320	9.060	24.400	2.340	8.990	24.500	2.339	9.040	24.730	2.400	8.920	25.300	2.220	9.680	26.400
04MD004	4.250	−0.270	0.610	3.450	−0.070	0.620	2.369	0.309	0.599	3.340	0.100	0.700	6.060	−0.230	0.770
04ME002	3.460	−0.930	88.700	4.420	12.570	121.200	5.790	16.754	152.630	5.240	39.300	164.100	3.650	78.900	173.600
04ME003	2.220	−15.040	93.720	5.310	−25.500	150.100	2.201	111.300	182.910	2.510	125.400	197.600	3.010	125.700	215.600
04MF001	0.800	2.670	8.110	0.780	2.690	8.110	7.993	−4.069	7.815	0.700	2.760	8.140	0.610	2.920	8.170
05QE008	1.120	1.690	4.420	1.130	1.700	4.460	9.849	−6.597	5.169	1.560	1.300	4.810	1.550	1.320	4.900
05QE009	1.440	0.620	3.190	1.470	0.610	3.220	1.524	0.588	3.286	1.610	0.540	3.380	1.640	0.530	3.530

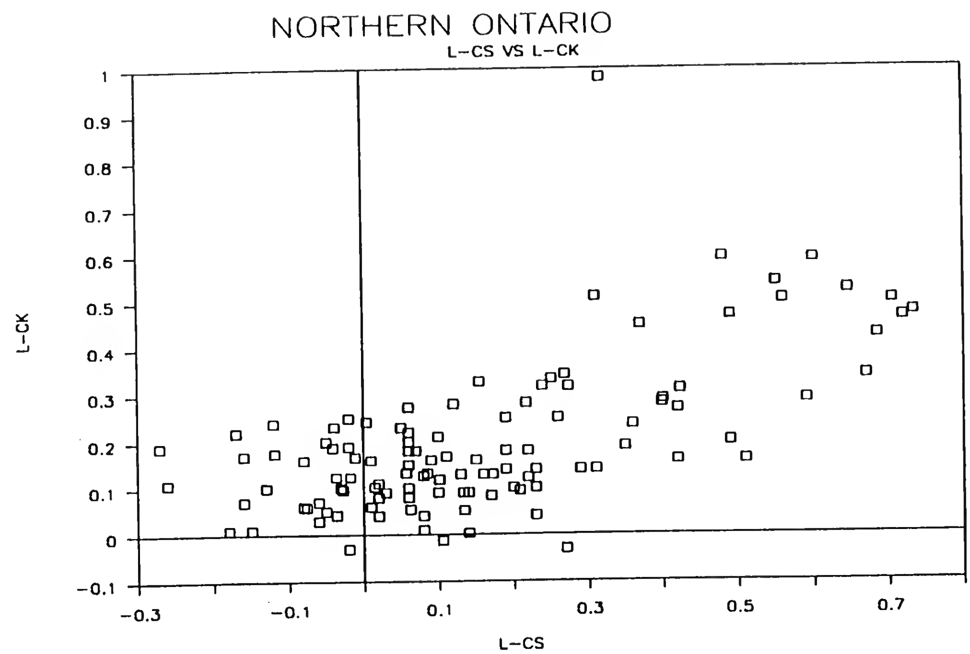


Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

L-CS vs. L-CV
NORTHERN ONTARIO

FIGURE B.1

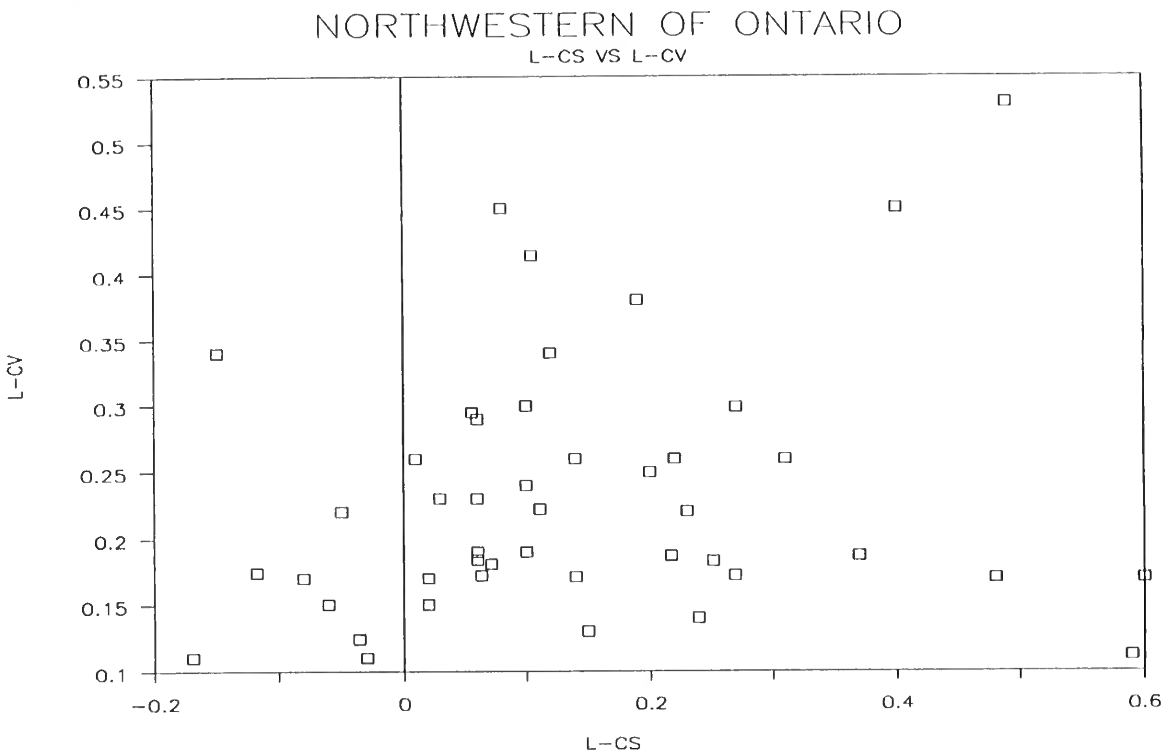


Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

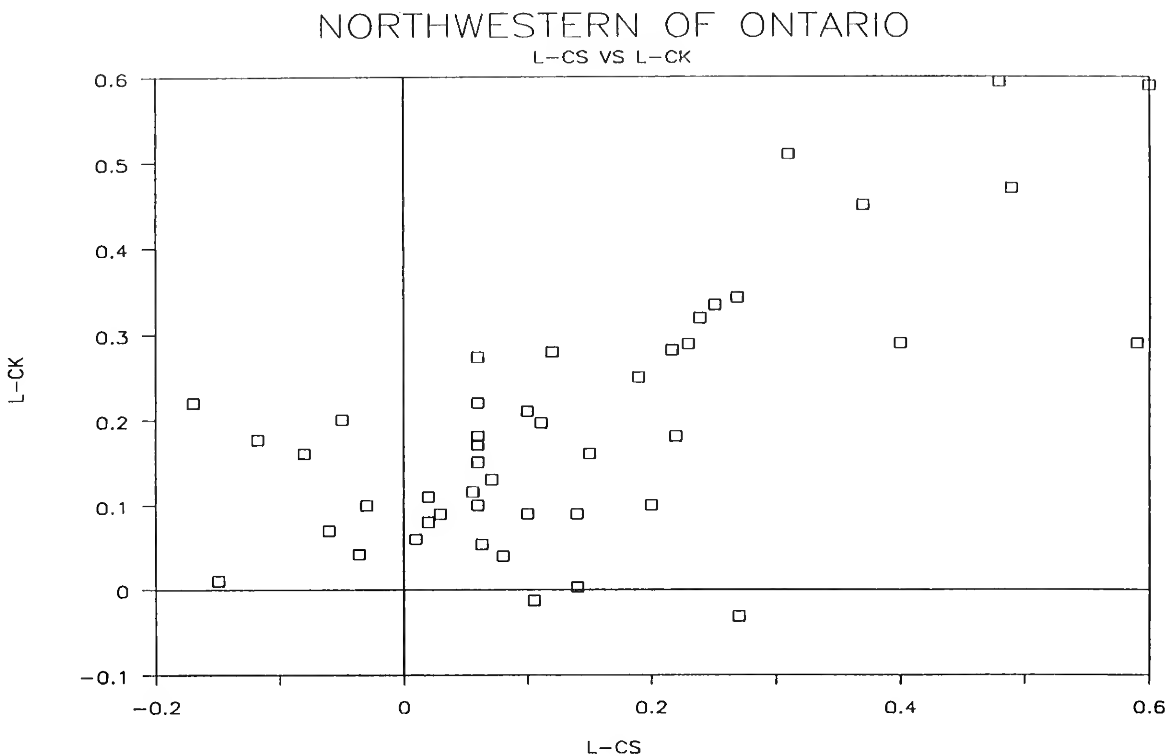
REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

L-CS vs. L-CK
NORTHERN ONTARIO

FIGURE B 2



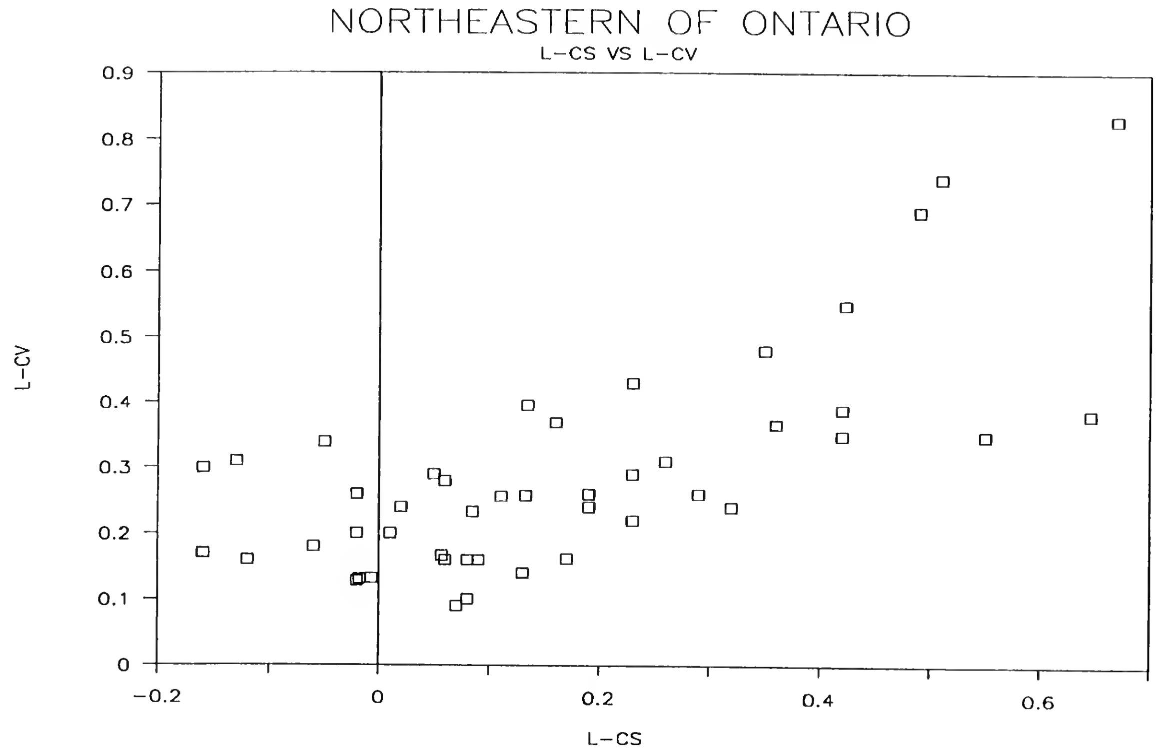
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	L-CS vs. L-CV NORTHWESTERN OF ONTARIO FIGURE B 3



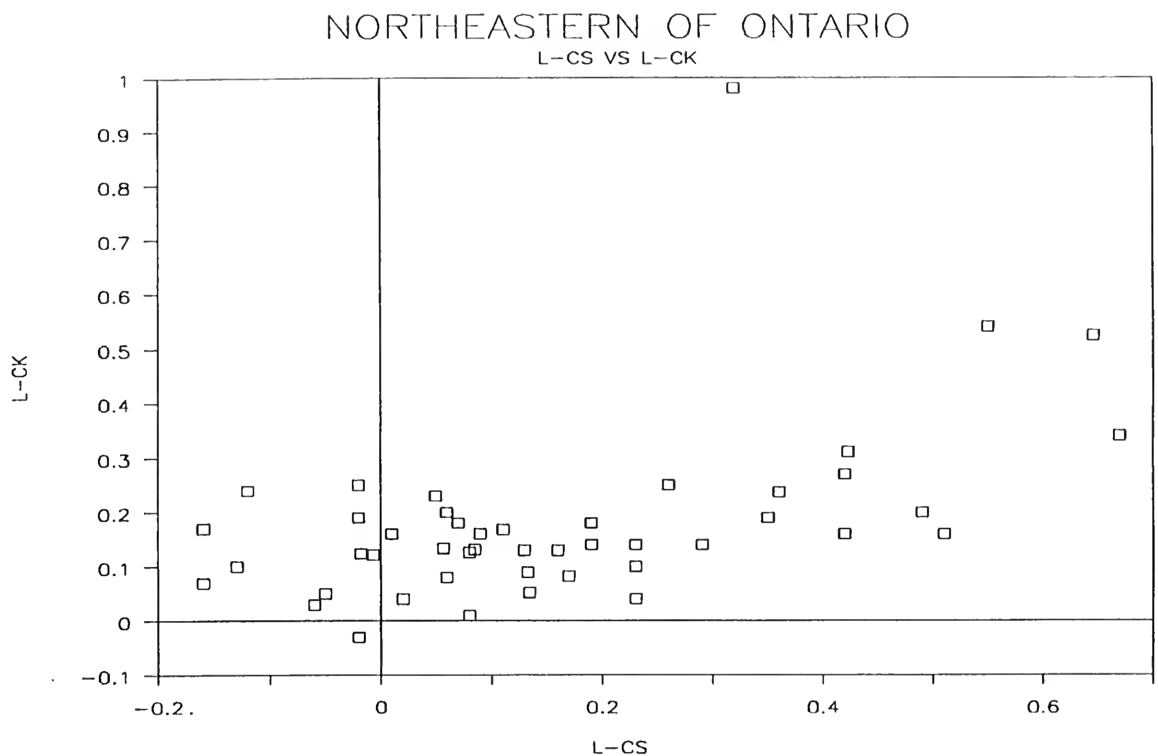
Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

L-CS vs. L-CK
NORTHWESTERN OF ONTARIO
FIGURE B.4



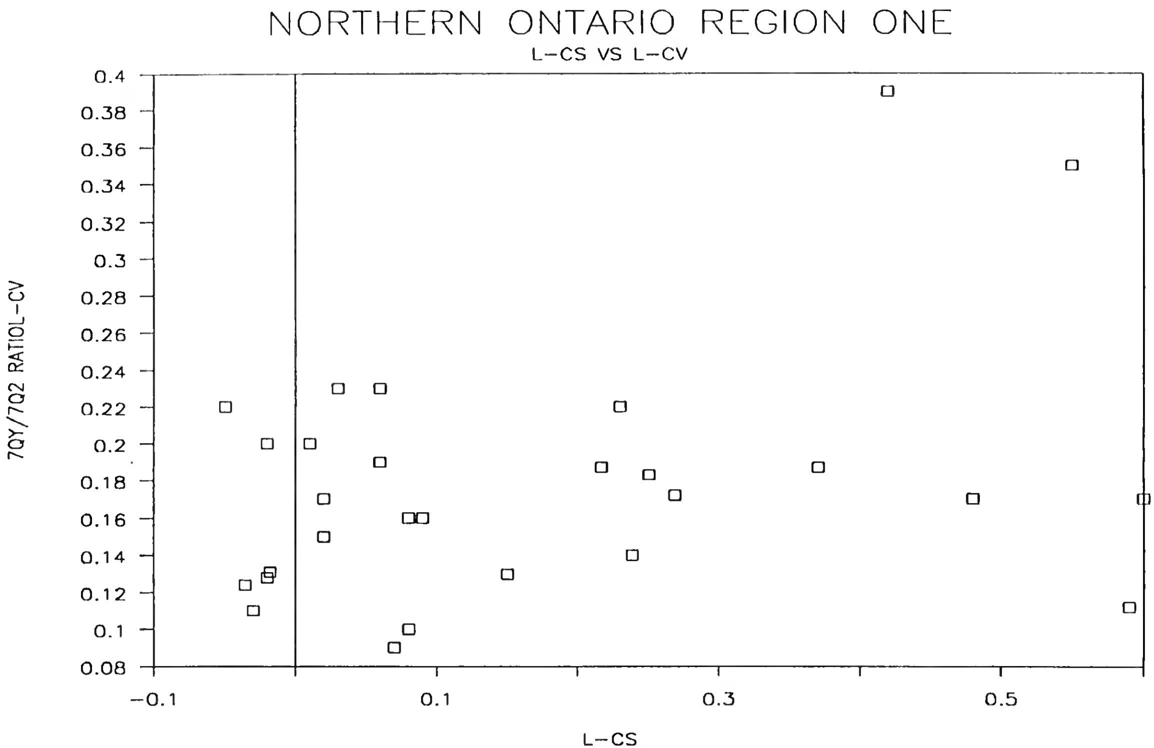
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	L-CS vs. L-CV NORTHEASTERN OF ONTARIO FIGURE B 5



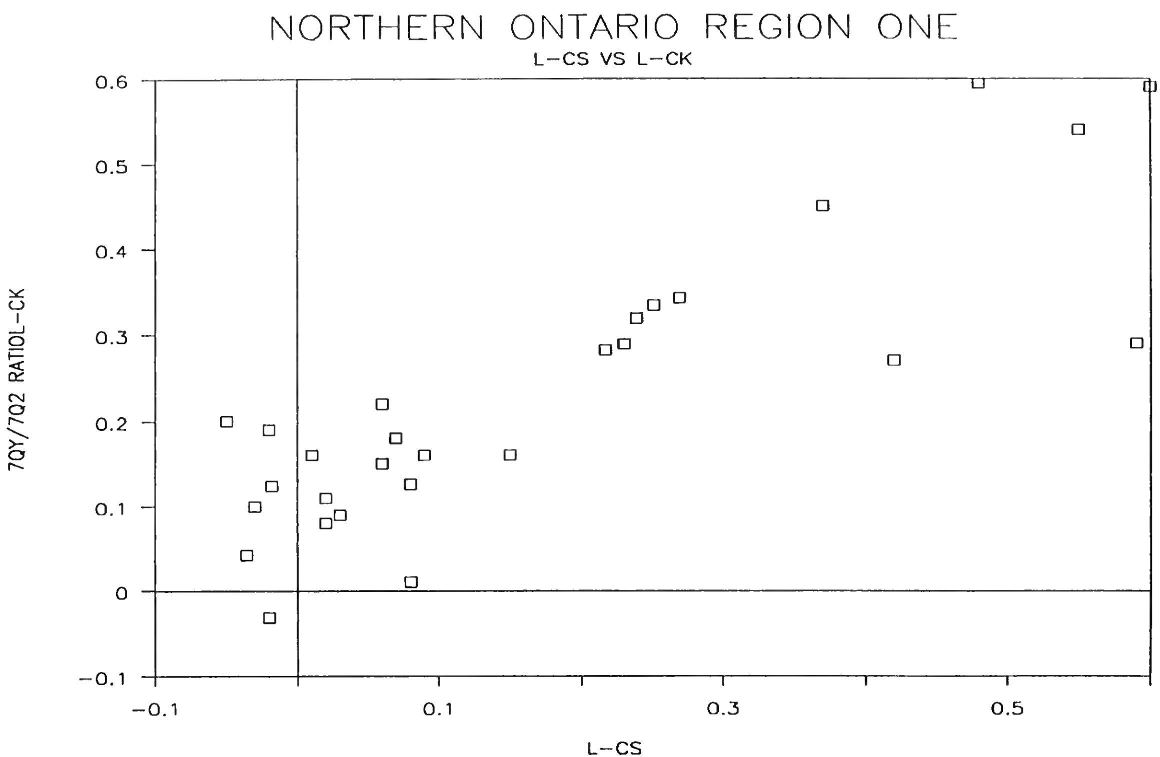
Cumming Cockburn
Consulting Engineers, Planners

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN

L-CS vs. L-CK
NORTHEASTERN OF ONTARIO



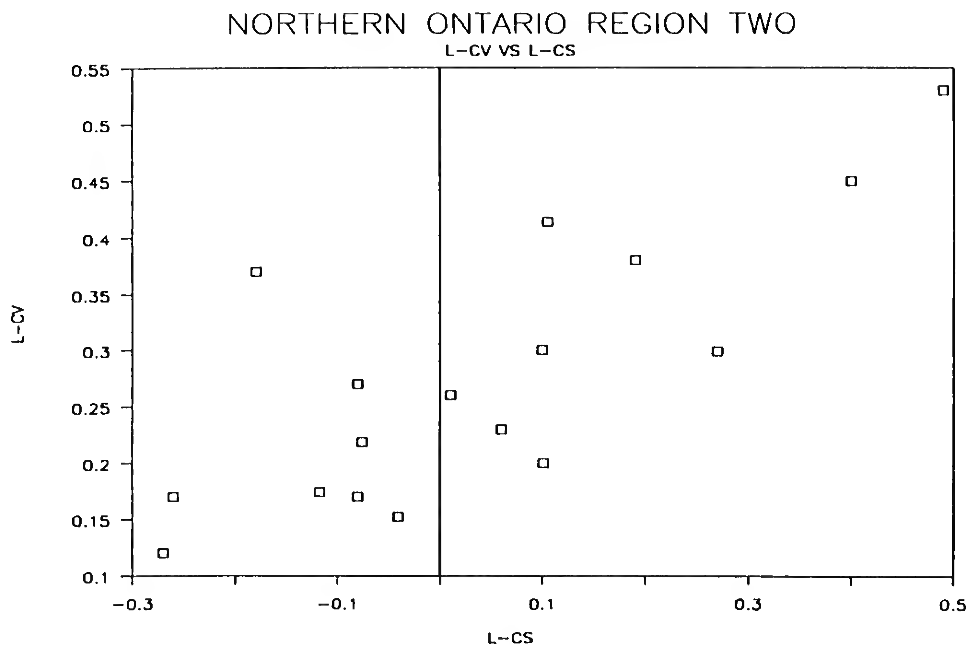
Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	L-CS vs. L-CV NORTHERN ONTARIO REGION ONE FIGURE B.7



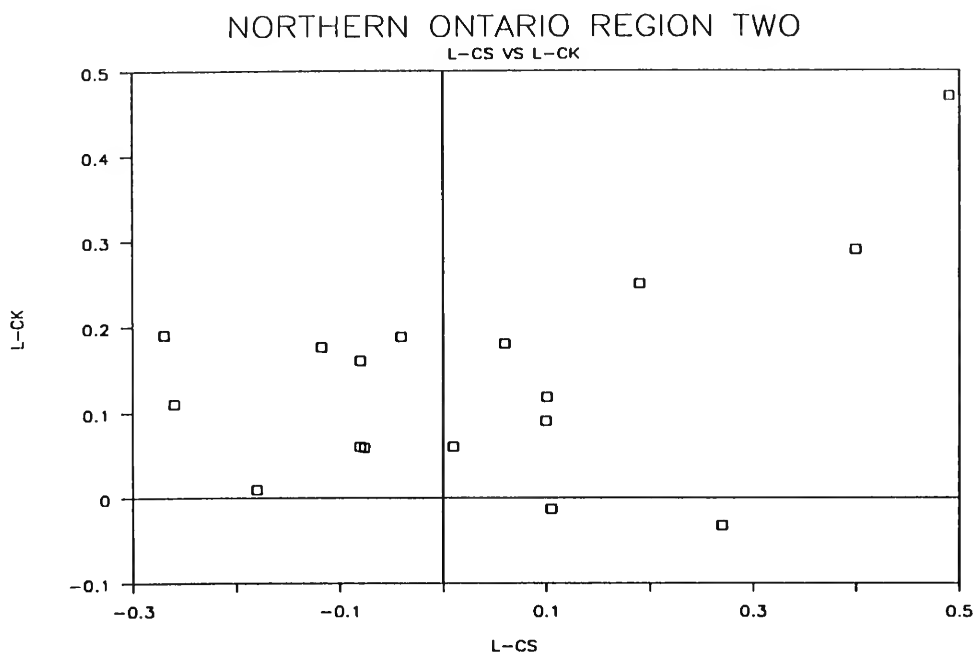
Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

L-CS vs. L-CK
NORTHERN ONTARIO REGION ONE
FIGURE B.8



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	L-CV vs. L-CS NORTHERN ONTARIO REGION TWO FIGURE B.9

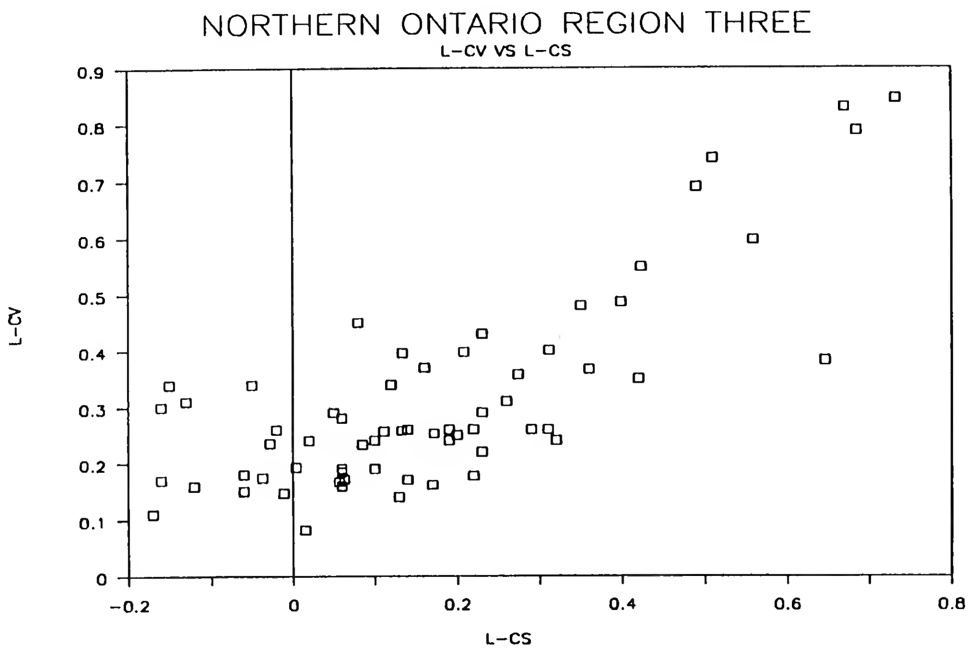


Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

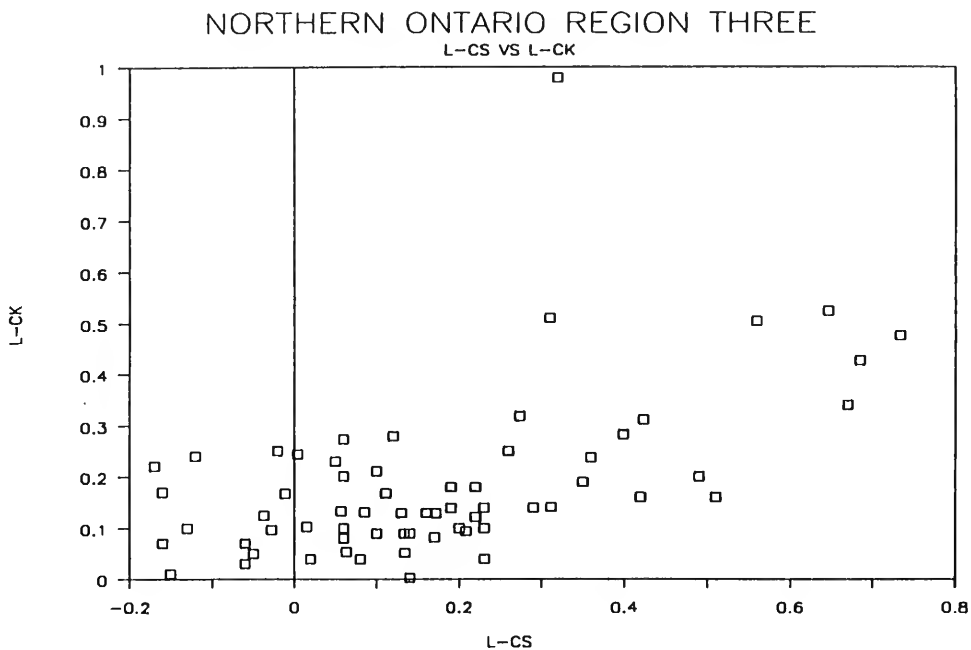
REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

L-CS vs. L-CK
NORTHERN ONTARIO REGION TWO

FIGURE B.10



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	L-CV vs. L-CS NORTHERN ONTARIO REGION TWO FIGURE B 11



CCL	**Cumming Cockburn** Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	L-CS vs. L-CK NORTHERN ONTARIO REGION THREE FIGURE B.12

APPENDIX C

WINTER/SUMMER/ANNUAL LOW FLOW POPULATION ANALYSIS

APPENDIX C

WINTER/SUMMER/ANNUAL LOW FLOW POPULATION ANALYSIS

Winter/Summer/Annual Low Flow Population Analysis

From the literature review it is apparent that seasonal low flows may belong to distinct populations. Further investigations were undertaken to assess this possibility. For the purposes of this investigation summer is defined by the period of May to October, and Winter is defined by the period of November to April. The low flows for winter and summer were then extracted for each station. The analysis results are given in the following Tables.

To analyze the low flow populations in winter, summer, and annual, the mean values and the standard deviations, for each low flow series over the recorded period of each station, were computed and compared. Table C.1 presents the comparison of the means and standard deviation for each of the stations in Northern Ontario Regions. Table C.2 tabulates the Mann-Kendall trend testing results. From Table C.1, it is clear that significant differences can be found among the statistics of annual/winter/summer low flow records. As an example, station 05QE006's mean annual low flow is equal to 88.25 m^3/s with standard deviation 45.82 m^3/s. The mean value of low flows for winter and summer are 131.74 and 105.56 m^3/s with standard deviation 63.46 and 61.06 m^3/s, respectively. It is interesting to note that the flow time series for winter displayed significant upward trend, but the summer low flow sequence showed downward trend.

Generally, it was found that the summer low flows are higher than the low flows from winter at most of the stations. The mean summer low flow of the entire region is equal to 46.2 m^3/s, while the mean winter low flow is 32.9 m^3/s. However, with reference to the raw data records, it is known that some winter low flows were measured under ice conditions. Therefore, the accuracy of flow measurements may not be comparable for summer and winter conditions.

For the purposes of the regional analysis, the annual low flow series was used since more conservative results should be obtained. However, for cases where assessment of seasonal discharges is important, a low flow analysis on a seasonal basis should be considered.

When undertaking the seasonal analysis, the relative frequency of the annual flow by season of occurrence was also analysed. The highest frequency of occurrence for the annual low flow from the available data set was found to occur in March and September (about 17 - 18% of the time for each month). This appears to be more or less constant over the time period of the available record. However, for the remaining samples it was also found, that in a general sense, there appears to be some noticeable shift in the time period of occurrence of low flow on an annual basis, with approximately a 20% shift in frequency of occurrence from colder months to warmer months during the year. The main change was observed to occur in the months of October, November and December where recent sampling shows about a 5% reduction in frequency of occurrence of low flows (i.e. comparing recent and earlier records) for each month. Further seasonal analyses should give some consideration to possible factors (climatic variations? changes in data collection methods?) and statistical implications of such changes.

TABLE C.1(a)
COMPARISON OF WINTER/SUMMER/ANNUAL FLOWS
NORTHWESTERN REGION

Station Number	# of Years	Region Code	Year		Winter		Summer	
			Mean	S.D.	Mean	S.D.	Mean	S.D.
02AA001	68	3	2.12	0.92	2.48	1.12	3.33	2.19
02AB006	64	3	25.11	8.32	32.4	11.43	28.1	9.37
02AB009	34	3	5.04	2.24	6.91	2.77	6.68	3.78
02AB010	68	3	21.82	7.44	28.37	9.09	24.19	8.41
02AB014	19	3	0.08	0.05	0.17	0.11	0.1	0.07
02AB015	14	3	0.57	0.26	0.72	0.3	0.84	0.47
02AB016	14	3	0.06	0.05	0.08	0.07	0.2	0.26
02AC001	20	3	0.7	0.32	0.91	0.58	1.42	0.96
02AD010	20	3	0.88	0.23	0.97	0.21	1.63	0.822
02AE001	17	3	0.92	0.55	0.92	0.29	1.5	1.04
02BA002	21	3	2.7	0.8	3.15	0.98	4.98	2.68
02BB002	24	3	3.965	1.595	4.55	1.18	7.3	3.03
02BB003	21	3	7.474	2.205	8.23	2.89	15.38	7.11
04CA002	14	1	97.18	27.84	102.6	46.21	204.87	84.46
04CA003	24	1	0.64	0.26	0.76	0.36	1.98	1.92
04CB001	24	1	43.58	11.16	45.26	10.96	84.14	31.17
04CC001	19	1	168.6	44.2	173.02	47.31	428.18	244.93
04CE002	23	1	23.62	4.4	24.61	4.22	27.83	5
04DA001	25	1	9.88	3.96	9.65	2.58	31.75	16.67
04DC001	14	1	96.33	17.74	106.1	58.07	233.74	132.8
04DC002	24	1	2.66	1.05	2.7	1.07	11.05	10.72
04FA001	25	1	16.91	5.58	16.96	3.81	58.38	37.13
04FB001	24	1	48.11	11.88	51.28	8.75	151.99	63.91
04FC001	23	1	57.96	12.04	59.86	12.13	175.82	93.03
04GA002	23	3	14.02	8.43	19.82	4.53	30.86	13.37
04GB004	20	3	41.42	8.94	41.57	8.3	66.77	27.82
04GC002	16	1	17.74	6.93	18.51	9.78	37.37	25.34
04GD001	22	1	55.98	15.48	70.18	36.07	160.66	106.63
04JA002	37	1	10.61	3.18	11.17	3.54	18.1	8.75
04JC002	41	1	4.45	1.45	4.67	1.35	8.51	4.91
04JF001	22	1	12.96	2.94	13.53	6.22	28.28	14.77
05PA012	64	2	10.35	4.17	11.01	4.66	15.04	7.05
05PB009	28	2	12.94	10.84	23.91	10.01	16.2	13.1
05PC018	11	2	145.84	46.62	168.31	60.4	187.42	65.37
05PC019	86	2	74.87	23.57	137.75	53.69	146.45	54.15
05QA001	60	2	48.78	14.7	49.5	14.93	72.96	31.08
05QA002	70	2	21.15	7.16	21.77	6.95	33.12	18.47
05QD003	27	2	8.59	4.38	9.12	13.28	9.39	6.01
05QD006	28	2	19.51	8.83	22.58	7.58	24.98	10.16
05QD016	21	2	4.96	4.5	13.33	32.62	16.4	45.13
05QE006	49	2	88.25	45.82	131.74	63.46	105.56	61.06
05QE007	35	2	150.86	78.84	223.17	106.38	167.18	86.55
05QE008	21	2	4.39	2.03	4.96	1.99	6.96	3.26
05QE009	31	2	0.03	1.57	3.53	1.63	4.69	2.97

TABLE C.1(b)
COMPARISON OF WINTER/SUMMER/ANNUAL FLOWS
NORTHEASTERN REGION

Station Number	# of Years	Region Code	Year		Winter		Summer	
			Mean	S.D.	Mean	S.D.	Mean	S.D.
02BF001	24	3	3.78	1.94	4.94	1.6	4.51	1.82
02BF002	24	3	2.86	1.79	4.04	1.46	3.45	1.9
02CA002	20	3	0.08	0.06	0.32	0.16	0.1	0.06
02CC007	41	3	18.82	11.22	31.83	17.33	24.99	12.19
02CC008	40	3	34.42	20.09	41.42	31.77	37.55	11.37
02CC009	31	3	33.04	16.96	44.13	24.2	38.2	8.2
02CD001	25	3	3.06	1.9	7.59	3.61	3.45	2.15
02CD006	23	3	0.652	0.291	1.25	0.38	0.77	0.3
02CE001	44	3	43.95	13.57	61.25	15.34	49.99	14.31
02CE002	76	3	4.08	1	5.51	1.95	4.58	1.53
02CF007	31	3	0.523	0.15	0.72	0.22	0.61	0.21
02CF010	15	3	1.84	0.8	3.09	0.8	2.24	1.19
02DC003	70	3	30.32	12.38	41.02	14.13	33.26	13.15
02DC008	52	3	1.73	3.43	4.17	6.57	4.95	5.96
02DD005	47	3	2.33	1.15	4.61	1.5	2.45	1.31
02DD009	35	3	1.57	0.68	2.51	0.71	1.75	0.76
02DD010	30	3	47.06	18.48	124.02	44.69	47.73	19.48
02DD013	17	3	0.06	0.03	0.15	0.05	0.07	0.04
02DD015	17	3	0.17	0.12	0.49	0.09	0.19	0.22
02EA005	76	3	0.8	0.43	1.75	0.52	0.91	0.6
02EA006	76	3	1.97	0.97	4	1.62	2.18	1.23
02EA010	23	3	0.41	0.19	0.74	0.27	0.47	0.22
02EA013	11	3	0.03	0.04	0.74	0.53	0.03	0.05
02JC008	23	3	3.94	1.1	4.29	1.73	4.11	2.14
02JE018	12	3	0.05	0.05	0.13	0.04	0.05	0.05
02JE019	19	3	3.99	1.82	6.83	2.1	4.93	3.3
02JE020	20	3	1.95	1.34	5.46	1.38	2.01	1.4
04KA001	21	1	1.43	0.95	1.45	1.13	8.45	5.99
04LF001	73	1	12.17	4.36	12.89	4.47	20.55	12.14
04LG002	24	1	164.98	42.42	176.58	44.17	247.11	94.06
04LM001	19	1	22.95	6.49	23.29	9.89	50.19	22.58
04MD004	14	1	0.58	0.19	0.62	0.19	0.71	0.4
04ME002	59	1	142.71	25.22	155.91	26.59	155.43	26.8
04MF001	25	1	7.53	3.5	9.12	8.65	26.75	15.12

TABLE C.2(a)
MANN–KENDALL TEST FOR TREND (7 Days Low Flow)
NORTHWESTERN REGION

Station	Annual				Winter				Summer			
			Indicator				Indicator				Indicator	
Number	tau	Z_m	5%	1%	tau	Z_m	5%	1%	tau	Z_m	5%	1%
2AA001	0.15	1.732	No	No	0.178	2.052	Yes	No	0.079	0.913	No	No
2AB004	−0.148	−1.714	No	No	−0.198	−2.283	Yes	No	−0.164	−1.892	No	No
2AB006	−0.118	−1.287	No	No	0.024	0.255	No	No	−0.159	−1.735	No	No
2AB008	0.25	2.03	Yes	No	0.167	1.348	No	No	0.256	2.076	Yes	No
2AB009	0.197	1.48	No	No	−0.133	−0.994	No	No	0.138	1.032	No	No
2AB010	0.045	0.51	No	No	0.149	1.72	No	No	−0.07	−0.807	No	No
2AB011	0.085	0.97	No	No	0.107	1.227	No	No	0.016	0.176	No	No
2AB013	−0.313	−2.627	Yes	Yes	−0.272	−2.287	Yes	No	−0.324	−2.727	Yes	Yes
2AB014	0.152	0.743	No	No	0.314	1.584	No	No	0.095	0.446	No	No
2AB015	−0.165	−0.767	No	No	−0.055	−0.219	No	No	−0.121	−0.548	No	No
2AB016	0.154	0.712	No	No	0.231	1.096	No	No	0.209	0.986	No	No
2AC001	0.13	0.676	No	No	−0.1	−0.495	No	No	0.05	0.225	No	No
2AC002	0.029	0.099	No	No	0.067	0.297	No	No	−0.314	−1.584	No	No
2AD008	−0.33	−2.82	Yes	Yes	−0.256	−2.179	Yes	No	−0.259	−2.207	Yes	No
2AD009	0.045	0.425	No	No	−0.042	−0.394	No	No	0.093	0.88	No	No
2AD010	−0.105	−0.495	No	No	0.124	0.594	No	No	−0.181	−0.891	No	No
2AE001	0.455	1.992	Yes	No	0.152	0.618	No	No	0.303	1.305	No	No
2BA002	−0.059	−0.288	No	No	0	0	No	No	0.015	0.041	No	No
2BA003	0.165	0.766	No	No	0.143	0.658	No	No	0.033	0.11	No	No
2BB002	−0.135	−0.77	No	No	−0.228	−1.329	No	No	0.053	0.28	No	No
2BB003	0.033	0.135	No	No	0.033	0.135	No	No	−0.05	−0.225	No	No
2BC004	0.252	1.786	No	No	−0.098	−0.683	No	No	0.206	1.455	No	No
4CA002	−0.19	−1.061	No	No	−0.19	−1.061	No	No	0.007	0	No	No
4CA003	0.292	−1.741	No	No	0.316	1.854	No	No	0.041	0.21	No	No
4CA004	−0.268	−1.515	No	No	−0.229	−1.288	No	No	−0.059	−0.303	No	No
4CB001	−0.368	−2.169	Yes	No	−0.38	−2.239	Yes	No	−0.123	−0.7	No	No
4CC001	0.103	0.428	No	No	0.103	0.428	No	No	0	0	No	No
4CE002	0.039	0.189	No	No	0.046	0.227	No	No	0.085	0.455	No	No
4DA001	−0.295	−1.784	No	No	−0.295	−1.784	No	No	−0.158	0.941	No	No
4DB001	0.247	4.492	No	No	0.247	1.492	No	No	0.289	1.752	No	No
4DC001	−0.297	−1.525	No	No	−0.324	−1.772	No	No	−0.015	−0.041	No	No
4DC002	0.013	0.038	No	No	0.013	0.038	No	No	0.059	0.303	No	No
4EA001	−0.02	−0.076	No	No	−0.02	−0.076	No	No	−0.111	−0.606	No	No
4FA001	0.253	−1.53	No	No	−0.221	−1.33	No	No	−0.3	1.87	No	No
4FA002	−0.263	−1.539	No	No	−0.24	−1.399	No	No	−0.38	−2.239	Yes	No
4FA003	−0.409	−2.414	Yes	No	−0.409	−2.414	Yes	No	−0.421	−2.484	Yes	No
4FB001	−0.058	−0.324	No	No	−0.058	−0.324	No	No	−0.095	−0.552	No	No
4FC001	−0.105	−0.595	No	No	−0.105	−0.595	No	No	−0.158	−0.91	No	No
4GA001	−0.625	−6.465	Yes	Yes	−0.573	−5.921	Yes	Yes	−0.651	−6.733	Yes	No
4GA002	0.15	−0.766	No	No	−0.15	−0.766	No	No	−0.133	−0.676	No	No
4GB001	−0.026	−0.245	No	No	−0.072	−0.685	No	No	−0.052	−0.489	No	No
4GB004	0.124	0.594	No	No	0.162	0.792	No	No	−0.124	−0.594	No	No

TABLE C.2(a)
MANN–KENDALL TEST FOR TREND (7 Days Low Flow)
NORTHWESTERN REGION

Station Number	Annual				Winter				Summer			
	tau	Z_m	Indicator		tau	Z_m	Indicator		tau	Z_m	Indicator	
			5%	1%			5%	1%			5%	1%
04GC002	−0.286	−0.693	No	No	−0.2	−0.99	No	No	0.086	0.396	No	No
04GD001	−0.311	−1.882	No	No	−0.316	−1.914	No	No	−0.179	−1.071	No	No
04HA001	−0.085	−0.455	No	No	−0.085	−0.455	No	No	−0.203	−1.136	No	No
04JA002	−0.019	−0.15	No	No	−0.038	−0.313	No	No	0.098	0.831	No	No
04JC002	0.162	1.376	No	No	0.181	1.539	No	No	0.149	1.267	No	No
04JC003	−0.09	−0.763	No	No	−0.038	−0.313	No	No	−0.03	−0.245	No	No
04JD002	−0.224	2.24	Yes	No	−0.224	2.24	Yes	No	−0.289	−2.889	Yes	Yes
04JD003	−0.134	−1.333	No	No	0.056	0.551	No	No	−0.066	−0.658	No	No
04JD005	−0.094	−0.525	No	No	0.018	0.07	No	No	−0.181	−1.05	No	No
04JF001	−0.235	−1.277	No	No	−0.235	−1.277	No	No	−0.118	−0.618	No	No
05PA006	0.213	2.485	Yes	No	0.229	2.665	Yes	Yes	0.171	1.993	Yes	No
04JG001	−0.125	−0.77	No	No	−0.099	−0.56	No	No	−0.088	−0.49	No	No
05PA012	0.095	1.053	No	No	0.182	2.034	Yes	No	0.05	0.549	No	No
05PB009	−0.269	−1.77	No	No	−0.095	−0.608	No	No	−0.289	−1.902	No	No
05PB014	0.233	2.693	Yes	Yes	0.26	3.001	Yes	Yes	0.128	1.477	No	No
05PC018	0.147	1.623	No	No	0.319	3.528	Yes	Yes	−0.022	−0.235	No	No
05PC019	0.032	0.416	No	No	0.167	2.198	Yes	No	−0.081	−1.06	No	No
05PD015	−0.343	−1.733	No	No	−0.305	−1.535	No	No	−0.343	−1.733	No	No
05PD017	0	0	No	No	−0.038	−0.149	No	No	−0.19	−0.941	No	No
05PD023	−0.343	−1.733	No	No	0.552	2.822	Yes	Yes	−0.371	−1.881	No	No
05PE005	0.229	1.288	No	No	0.15	0.833	No	No	0.163	0.909	No	No
05PE006	0.437	5.69	Yes	Yes	0.468	6.1	Yes	Yes	0.375	4.89	Yes	Yes
05PE011	0.161	2.014	Yes	No	0.281	3.515	Yes	Yes	0.111	1.381	No	No
05QA001	0.06	0.676	No	No	0.073	0.816	No	No	0.003	0.032	No	No
05QA002	0.123	1.44	No	No	0.196	2.304	Yes	No	0.078	0.917	No	No
05QA004	−0.087	−0.584	No	No	−0.037	−0.234	No	No	−0.12	−0.817	No	No
05QB006	0.046	0.339	No	No	0.062	0.464	No	No	−0.002	0	No	No
05QC001	−0.076	−0.496	No	No	0	0	No	No	−0.087	0.57	No	No
05QC003	−0.324	−1.772	No	No	−0.368	−2.019	Yes	No	−0.176	−0.948	No	No
05QD003	−0.187	−1.085	No	No	−0.205	−1.19	No	No	−1.175	−1.015	No	No
05QD006	−0.068	−0.542	No	No	−0.011	−0.077	No	No	−0.095	−0.759	No	No
05QE006	−0.091	1.181	No	No	0.246	3.205	Yes	Yes	0.167	−2.172	Yes	No
05QE007	−0.154	−1.178	No	No	−0.136	−1.035	No	No	−0.094	−0.714	No	No
05QE008	−0.5	−2.761	Yes	No	−0.515	−2.843	Yes	Yes	0.191	−1.03	No	No
05QE009	−0.094	−0.62	No	No	−0.174	−1.166	No	No	−0.094	−0.62	No	No

Yes – There is a Trend
No – No Trend

TABLE C.2(b)
MANN–KENDALL TEST FOR TREND (7 Days Low Flow)
NORTHEASTERN REGION

Station	Annual				Winter				Summer			
			Indicator				Indicator				Indicator	
Number	tau	Z_m	5%	1%	tau	Z_m	5%	1%	tau	Z_m	5%	1%
02BD002	0.389	4.34	Yes	Yes	0.441	4.924	Yes	Yes	0.339	3.786	Yes	Yes
02BD003	0.009	−0.044	No	No	0.028	0.176	No	No	−0.058	−0.397	No	No
02BE002	0.398	4.11	Yes	Yes	0.407	4.207	Yes	Yes	0.463	4.784	Yes	Yes
02BF001	0.076	0.42	No	No	0.123	0.7	No	No	−0.088	−0.49	No	No
02BF002	−0.018	−0.07	No	No	0.076	0.42	No	No	−0.053	−0.28	No	No
02CA002	0.067	0.297	No	No	0.181	0.891	No	No	0.067	0.297	No	No
02CC005	−0.021	−0.192	No	No	0.047	435	No	No	0.027	0.253	No	No
02CC008	0.448	3.584	Yes	Yes	0.373	2.984	Yes	Yes	0.413	3.308	Yes	Yes
02CD001	0.011	0.032	No	No	0.053	0.292	No	No	0.011	0.032	No	No
02CD006	0.055	0.156	No	No	0.091	0.311	No	No	0.055	0.156	No	No
02CE001	−0.189	−1.625	No	No	0.225	1.949	No	No	−0.317	−2.747	Yes	Yes
02CE002	−0.012	−0.137	No	No	−0.069	−0.0842	No	No	0.008	0.091	No	No
02CE005	−0.195	−2.308	Yes	No	0.23	2.723	Yes	Yes	−0.205	−2.441	Yes	No
02CF004	−0.25	−3.007	Yes	Yes	0.155	−1.858	No	No	−0.248	−2.986	Yes	Yes
02CF005	−0.422	−3.064	Yes	Yes	0.274	−1.98	Yes	No	−0.553	−4.023	Yes	Yes
02CF007	−0.323	2.293	Yes	No	0.012	0.066	No	No	0.255	1.808	No	No
02CF008	−0.121	0.481	No	No	0.333	1.442	No	No	0.152	0.618	No	No
02CF009	−0.24	−1.66	No	No	−0.113	−0.771	No	No	−0.387	−2.686	Yes	Yes
02CF010	0.273	1.09	No	No	0.364	1.479	No	No	0.2	0.778	No	No
02CF011	−0.303	−1.305	No	No	−0.061	−0.206	No	No	−0.333	−1.442	No	No
02DB005	−0.314	−2.594	Yes	Yes	0.02	−0.148	No	No	−0.326	−2.698	Yes	Yes
02DC003	0.058	0.674	No	No	0.242	2.848	Yes	Yes	−0.03	−0.345	No	No
02DC004	0.179	1.293	No	No	0.151	1.084	No	No	0.003	0	No	No
02DC007	0.119	1.182	No	No	0.056	0.551	No	No	0.202	2.018	Yes	No
02DC008	0.166	1.653	No	No	0.07	0.693	No	No	0.308	3.075	Yes	Yes
02DD005	0.154	−1.522	No	No	0.221	2.183	Yes	No	−0.179	−1.761	No	No
02DD008	0.218	1.543	No	No	0.049	0.331	No	No	0.185	1.301	No	No
02DD009	−0.133	−0.994	No	No	0.18	1.351	No	No	−0.148	−1.107	No	No
02DD010	0.33	2.289	Yes	No	0.14	0.958	No	No	0.327	2.266	Yes	No
02DD012	0.308	1.405	No	No	0.282	1.283	No	No	0.436	2.016	Yes	No
02DD013	0.409	1.786	No	No	0.288	1.236	No	No	0.47	2.06	Yes	No
02DD015	0.333	1.442	No	No	0.045	0.137	No	No	0.333	1.442	No	No
02EA005	0.159	1.956	No	No	0.055	0.675	No	No	0.141	1.737	No	No
02EA006	−0.136	−1.678	No	No	0.204	2.517	Yes	No	−0.145	−1.787	No	No
02EA010	0.018	0.07	No	No	0.298	1.749	No	No	0.006	0	No	No
02EA011	0.179	0.794	No	No	0.141	0.611	No	No	0.385	1.771	No	No
02EA013	0.473	1.946	No	No	−0.018	0	No	No	0.473	1.946	No	No
02JC008	0.078	0.417	No	No	−0.052	−2.65	No	No	0.222	1.25	No	No
02JD009	0	0	No	No	0.265	1.442	No	No	0.059	−0.288	No	No
02JD012	0.449	4.122	Yes	Yes	0.495	4.549	Yes	Yes	0.295	2.707	Yes	Yes
02JE018	−0.255	−1.012	No	No	−0.055	−0.156	No	No	−0.309	−1.246	No	No
02JE019	0.086	0.396	No	No	−0.143	0.693	No	No	0.048	0.198	No	No

TABLE C.2(b)
MANN–KENDALL TEST FOR TREND (7 Days Low Flow)
NORTHEASTERN REGION

Station Number	Annual				Winter				Summer			
			Indicator				Indicator				Indicator	
	tau	Z_m	5%	1%	tau	Z_m	5%	1%	tau	Z_m	5%	1%
02JE020	−0.01	0	No	No	0.39	1.98	Yes	No	−0.01	0	No	No
04HA001	−0.085	−0.91	No	No	−0.085	0.455	No	No	−0.203	−1.136	No	No
04JA002	−0.019	−0.15	No	No	−0.038	−0.313	No	No	0.098	0.831	No	No
04JC002	0.162	1.376	No	No	0.181	1.539	No	No	0.149	1.267	No	No
04JC003	−0.09	−0.763	No	No	−0.038	0.313	No	No	0.03	−0.245	No	No
04KA001	0.017	0.045	No	No	0.017	0.045	No	No	0	0	No	No
04LB001	0.096	1.129	No	No	0.415	4.925	Yes	Yes	0.135	−1.594	No	No
04LD001	0.217	2.503	Yes	No	0.355	4.104	Yes	Yes	0.022	1.751	No	No
04LF001	−0.077	−0.926	No	No	−0.072	−0.868	No	No	0.057	−0.683	No	No
04LG002	−0.36	−2.377	Yes	No	−0.328	−2.166	Yes	No	0.289	−1.902	No	No
04LJ001	0.004	0.039	No	No	−0.013	−0.144	No	No	0.037	0.437	No	No
04LM001	0.077	0.305	No	No	0.103	0.428	No	No	−0.154	−0.672	No	No
04MD002	−0.213	−2.124	Yes	No	−0.186	−1.858	No	No	−0.072	−0.711	No	No
04MD004	0.778	3.014	Yes	Yes	0.556	2.147	Yes	No	0.6	2.326	Yes	No
04ME002	−0.029	−2.98	No	No	0.235	2.507	Yes	No	−0.082	−0.873	No	No
04ME004	−0.387	−2.686	Yes	Yes	−0.147	−1.004	No	No	−0.263	−1.822	No	No
04MF001	−0.374	−2.271	Yes	No	−0.374	−2.271	Yes	No	0.079	−0.454	No	No

APPENDIX D

STATISTICAL REGIONS

APPENDIX D
STATISTICAL REGIONS

Statistical Regions

Low flow estimation may be improved by identification of statistically homogeneous regions or sub-regions. Various statistical tests were applied to evaluate the identification of sub-regions. These test included the following:

1. Statistical Homogeneity Test (see Appendix D.1);
2. Heterogeneity Measure (see Appendix D.2); and
3. Cluster Analysis (see Appendix D.3).

The tests and relevant results are described in the following sub-sections.

APPENDIX D.1

STATISTICAL HOMOGENEITY TEST

APPENDIX D.1
STATISTICAL HOMOGENEITY TEST

Statistical Homogeneity Test

For every station, a low flow frequency analysis is performed based on the W3 distribution. Flows corresponding to specific return periods of nonexceedance can be made dimensionless by dividing by some chosen index low flow.

Within a homogeneous region, the dimensionless frequency curve at any station is considered a random sample. The best representation of the regional characteristics is obtained by averaging the dimensionless curves for all stations in the region. The resulting average dimensionless curve is the regional dimensionless frequency curve and is considered applicable throughout the region, providing the conditions of homogeneity are met. From equation (B - 3), any three low flows and their return periods of nonexceedance give three simultaneous transcendental equations which, when solved, yield parameters a, e and u. If the 2, 12.488, and 100-year low flows are selected, then the solution is simplified to the evaluation of the three functions. The value 12.488 is the mid-point between 2 and 100-year return periods in W3 reduced variate terms.

The procedure then is to find the median values of the dimensionless 12.488 and 100-year low flows in the region.

When the index low flows are selected as the 2-year low flows, the median dimensionless value of all the 2-year low flow is unity. The medians are then substituted into the following expressions to obtain the parameters of the regional dimensionless curve:

$$e = (Q_{100} - Q_{12.488}) / (1 + Q_{100} - 2Q_{12.488}) \tag{D - 1}$$

$$a = 4.23464 / \ln [(1-e) / (Q_{100}-e)] \tag{D - 2}$$

$$u = [(1-e) / 0.69315^{\frac{1}{a}}] + e \tag{D - 3}$$

For each station, the 10-year nonexceedance flow is tested by multiplying its estimated 2-year nonexceedance flow by the regional Q_{10} index ratio. Using the station analysis, the return period Y of the estimated 10-year nonexceedance flow X_{100} can be found from:

$$y = 1/ \{ 1 - \exp[- \exp(a \ln (X_{10}-e)/(u-e))]\} \tag{D - 4}$$

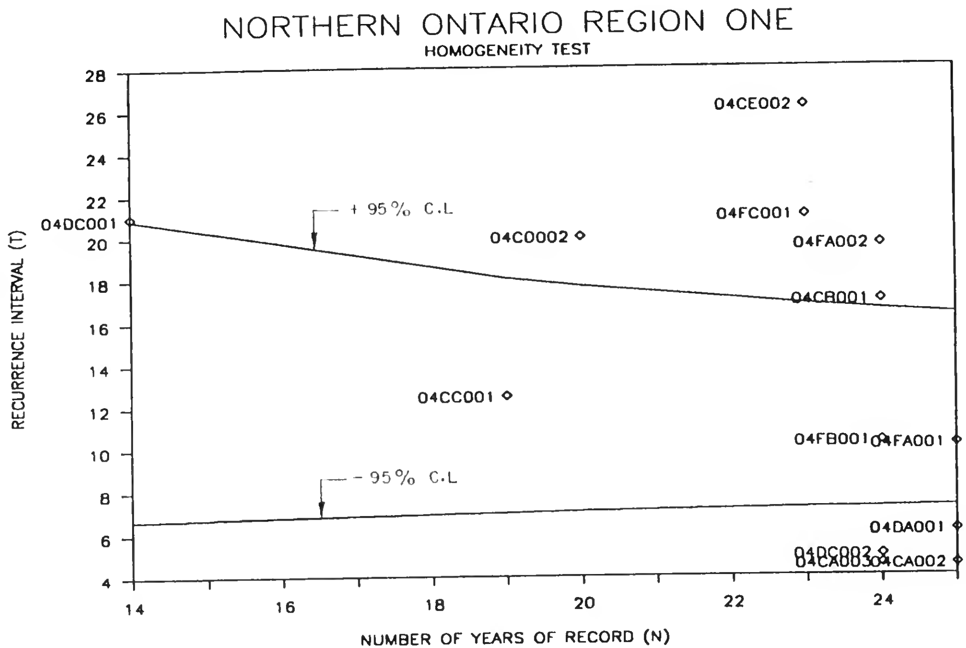
The value of y should fall within two standard errors of the return period for a given sample size N to be expected in random sampling from W3 distribution.

The following expression is used to estimate the standard error of the y-year nonexceedance. For the 10-year nonexceedance low flow:

$$y = 0.10536/N^{\frac{1}{2}} \qquad \text{(D - 5)}$$

From this relationship the approximate upper and lower 95% confidence limits can be computed for any sample size N. Thereafter, the corresponding upper and lower limits of the return period y_l and y_u can be calculated from equation (D - 4).

The results of the statistical homogeneity test for the three sub-regions in Northern Ontario (see Figure 3.4) are summarized on Figures D.1, D.2, and D.3. In all cases, a significant scatter of data above and below the ± 95% confidence limit band was found. This is attributed mainly to the shape of the probability density function. Generally, it was found that (compared to flood frequency curves) the low flow frequency curves are "flat", giving rise to significant estimating error in determining the recurrence interval for plotting using the available data and the procedures described above.

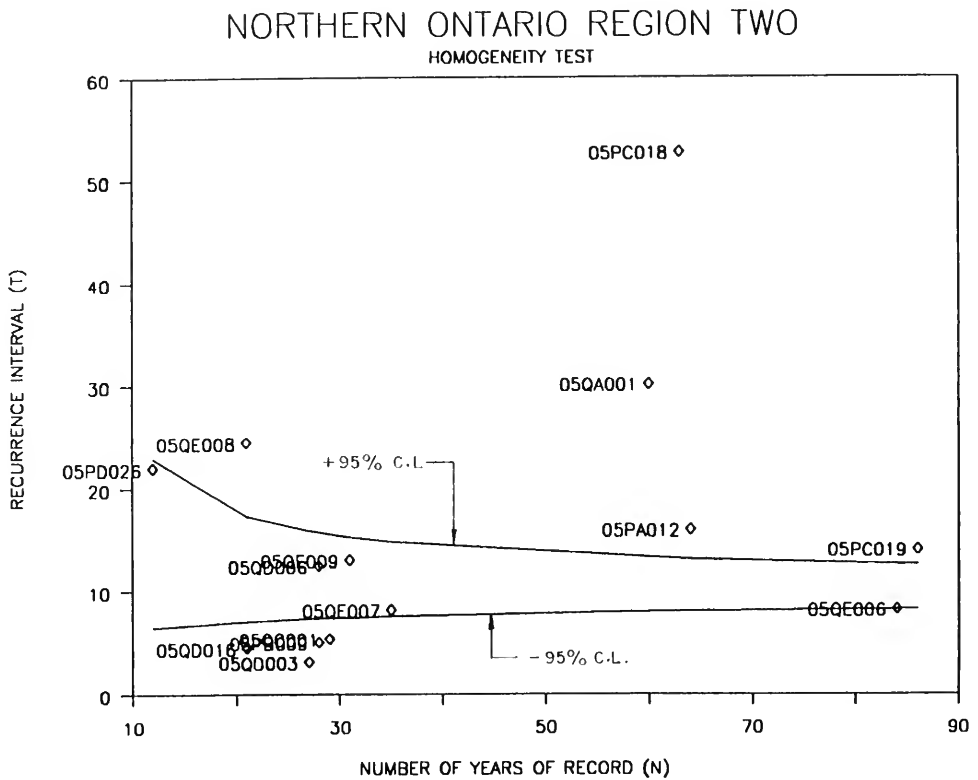


Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

HOMOGENEITY TEST
REGION ONE

FIGURE D 1



Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

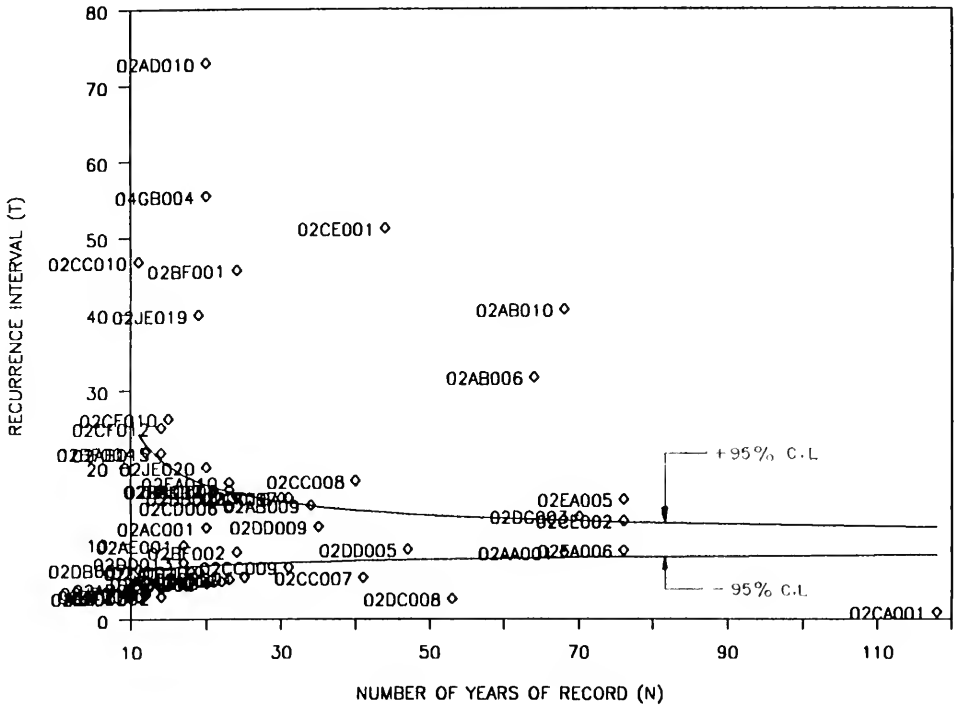
REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

HOMOGENEITY TEST
REGION TWO

FIGURE D.2

NORTHERN ONTARIO REGION THREE

HOMOGENEITY TEST



Cumming Cockburn Consulting Engineers, Planners and Environmental Scientists	REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO	HOMOGENEITY TEST REGION THREE FIGURE D 3

APPENDIX D.2
HETEROGENEITY MEASURE

APPENDIX D.2
HETEROGENEITY MEASURE

The purpose of this technique is to estimate the degree of heterogeneity in a group of sites and to assess whether they might reasonably be treated as a homogeneous region. Specifically, the heterogeneity measure compares the between-site variations in sample L-moments for the group of sites with what would be expected for a homogeneous region.

Heuristic Description

In a homogeneous region all sites have the same population L-moments. Their sample L-moments will, however, be different, owing to sampling variability. Thus a natural question to ask is whether the between-site dispersion of the sample L-moments for the group of sites under consideration is larger than would be expected of a homogeneous region.

A simple measure of the dispersion of the sample L-moments is the standard deviation of the at-site L-CVs. It is reasonable to concentrate on L-CV, since between-site variation of L-CV has a much larger effect than variations in L-skewness or L-kurtosis on the variance of the estimates of all quantiles $Q_i(F)$, except those in the far tail of the distribution with $F \geq 0.998$. To allow for the greater variability of L-moments in small samples, average should be weighted proportionally to the sites' record lengths.

To establish what "would be expected" a simulation technique could be used. By repeated simulation of a homogeneous region with sites having record lengths the same as those of the observed data, the mean and standard deviation of the chosen dispersions measure could be obtained. To compare the observed and simulated dispersions, an appropriate statistic is:

$$\frac{(\textit{Observed dispersion}) - (\textit{Mean of simulations})}{(\textit{Standard deviation of simulations})} \qquad \text{(D - 6)}$$

A large positive value of this statistic indicates that the observed L-moments are more dispersed than is consistent with the hypothesis of homogeneity.

Formal Definition

Calculate the weighted standard deviation of the at-site sample L-CVs.

$$V = \sum_{i=1}^{N} Ni\ (L - CV^{(i)} - L - CV)^2 \ / \sum_{i=1}^{N} Ni \qquad \text{(D - 7)}$$

Fit a Weibull distribution to the group average L-moments to obtain parameters a, e, and u.

Simulate a large number N_{sim} of groups from this Weibull distribution. For each simulation calculate V. From the simulations determine the mean and standard deviation of the N_{sim} values of V. Call these μ_v and σ_v. Calculate the heterogeneity measure.

$$H = \frac{(V - \sigma_v)}{\sigma_v} \tag{D - 8}$$

Declare the region to be heterogeneous if H is sufficiently larger. It is suggested that the region would be regarded as "acceptable homogeneous" if $H < 1$, "possibly heterogeneous" if $1 \leq H < 2$, and "definitely heterogeneous" if $H \geq 2$.

A summary of the results for 500 simulations is given in Table D.1.

The heterogeneity measure technique was found to confirm the homogeneity of the selected sub-regions in the sense of similar frequency distribution characteristics. The weighted standard deviation of the at-site sample L-CVs (represented by V in Table D.1) present the variations of the L-CV of the regions. The expected V and its standard deviation from the simulation give the range of variation of the V statistics. The heterogeneity measure, which is the H value in Table D.1, declares the region to be heterogeneous if H is sufficiently larger. The region would be regarded as "acceptable homogeneous" if $H < 1$, "possibly heterogeneous" if $1 \leq H < 2$, and "definitely heterogeneous" if $H \geq 2$. From Table D.1, it is evident that the database available for Northern Ontario is heterogeneous (because $H = 2.48$ and is larger than 2). The Northwestern and Northeastern regions could be defined as possibly the heterogeneous regions and the sub-regions could be viewed as homogeneous. Therefore it is concluded that, the regionalization techniques could be applied to the sub-regions with some confidence.

TABLE D.1

RESULTS OF HETEROGENEITY MEASURE (L-CV)

Region	V (recorded)	V^e (simulated)	Std. Dev. of V (simulated)	H
Northern Ontario	0.016	0.013	0.0014	2.48
Northwestern Ontario	0.024	0.019	0.0034	1.56
Northeastern Ontario	0.008	0.0065	0.0011	1.29
Sub-Region 1	0.0037	0.0031	0.00061	0.97
Sub-Region 2	0.0095	0.0083	0.0029	0.41
Sub-Region 3	0.022	0.020	0.0033	0.60

Note: $H < 1$ Homogeneous
$1 < H < 2$ Possibly Heterogeneous
$H > 2$ Heterogeneous
(500 simulations)
V weighted standard deviation of the at site L-CV's
V^e Simulated standard deviation of of L-CV
H Heterogeneity measure

APPENDIX D.3
CLUSTER ANALYSIS

APPENDIX D.3
CLUSTER ANALYSIS

Cluster Analysis

Cluster analysis is, basically, a pattern recognition procedure consisting of the following five steps.

1. choose the appropriate variables;
2. transform and standardize the variables, if necessary;
3. choose the appropriate distance or similarity measure;
4. choose the clustering algorithm; and
5. run the analysis and interpret the results.

Standardization

Variables may be standardized (Z values) by centering them about their mean ($\bar{x}$) and rescalling them by the reciprocal of their standard deviation(s):

$$Z = \frac{x - \bar{x}}{s} \tag{D - 9}$$

The standardized values are called Z values or Z scores. The unstandardized variables may have different units and may be scaled differently. When converted to Z scores the variables contribute equally to the cluster analysis. Weighting the variable equally is generally preferred unless there is a prior information identifying that some variables are more important than others.

Distance or Similarity Measure

Clustering methods begin with a matrix of distances or similarities between samples. This procedure produces an n x n matrix whose elements consist of the distance between, or similarity of, two samples. Many different definitions for distance have been defined. In this study, the following equation was used to evaluate the distance:

$$\text{Distance (A, B)} = \sqrt{\sum_{i=1}^{m} (A_i - B_i)^2} \tag{D - 10}$$

where Distance (A, B) is the distance between samples A and B.

Clustering Algorithm

Clustering algorithms may be either hierarchical or non hierarchical. Hierarchical algorithms produce dendograms that show the sample similarities. Non hierarchical algorithms produce groups directly. A hierarchical algorithm used in the analysis. The SPSS may produce clustering results based on the distance matrix.

Results and Conclusion

The cluster analysis was undertaken using all the variables identified suitable for regression analysis (see Table 3.8). The variables were not standardized because some of the variables, such as drainage area, stream length and the mean annual runoff, are more important than the others. Therefore, it is desirable that these variables have more effects on the clustering of low flow records. The results show that the drainage area dominated the clustering. This is consistent with the correlation analysis which indicate that the drainage areas are the most important parameter in estimating low flow characteristics.

The 93 stations were divided into two groups namely a Large Drainage Area group and a Small Drainage Area group. The 78 stations, whose DA < 17,000 km^2, may be classified into the small drainage area group. The remaining 15 stations, with larger drainage, belong to the cluster of Large Drainage Area.

The attached printouts show the results in more detail.

```
T /FILE 'C:\7354\BASET.SPS'.
e SPSS/PC+ system file is read from
  file C:\7354\BASET.SPS
e file was created on  8/14/92 at 12:20:35
d is titled                      SPSS/PC+
e SPSS/PC+ system file contains
   99 cases, each consisting of
   52 variables (including system variables).
   52 variables will be used in this session.
```

```
is procedure was completed at 14:42:54
```

```
USTER YEAR RN MAP MAS MAR EVA DA BFI LNTH ACL Q2 /ID NEMBER /PRINT
USTER (2,4) DISTANCE SCHEDULE /METHOD COMPLETE /MEASURE EUCLID /PLOT VICICLE
NDROGRAM.
USTER requires 30216 BYTES of workspace for execution.
```

---

* * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * *

ata Information

```
      99 unweighted cases accepted.
       0 cases rejected because of missing value.

uclidean measure used.

 Agglomeration method specified.

uclidean Dissimilarity Coefficient Matrix
```

---

luster Membership of Cases using Complete Linkage

Label	Case	Number of Clusters 4	3	2
02AA001 68 0 800 23	1	1	1	1
02AB006 64 1 785 23	2	1	1	1
02AB009 34 1 785 23	3	1	1	1
02AB010 68 1 785 23	4	1	1	1
02AB011 67 1 780 23	5	1	1	1
02AB014 19 0 780 24	6	1	1	1
02AB015 14 1 780 24	7	1	1	1
02AB016 14 1 780 23	8	1	1	1
02AC001 20 0 785 24	9	1	1	1
02AD009 48 1 780 25	10	1	1	1
02AD010 20 0 788 25	11	1	1	1
02AE001 17 0 805 24	12	1	1	1
02BA002 21 0 840 23	13	1	1	1
02BB002 24 0 875 24	14	1	1	1

02BB003	21	0	860	24	15	1	1	1
04GA002	23	0	720	23	16	1	1	1

Page 78 SPSS/PC+ 7/13/93

Number of Clusters

Label					Case	4	3	2
04GB004	20	0	740	26	17	1	1	1
04CA002	14	0	590	19	18	2	2	1
04CA003	24	0	590	20	19	1	1	1
04CA004	19	0	590	19	20	1	1	1
04CB001	24	0	590	20	21	1	1	1
04CC001	19	0	595	23	22	3	3	2
04CD002	20	0	550	19	23	1	1	1
04CE002	23	0	600	23	24	1	1	1
04DA001	25	0	650	24	25	1	1	1
04DC001	14	0	590	22	26	4	2	1
04DC002	24	0	500	21	27	1	1	1
04FA001	25	1	700	26	28	1	1	1
04FA002	24	1	700	26	29	1	1	1
04FB001	24	0	700	26	30	2	2	1
04FC001	23	0	650	23	31	2	2	1
04GC002	16	1	735	26	32	1	1	1
04GD001	22	1	710	25	33	2	2	1
04JA002	37	0	810	30	34	1	1	1

Page 79 SPSS/PC+ 7/13/93

Number of Clusters

Label					Case	4	3	2
04JC002	41	0	810	30	35	1	1	1
04JF001	22	0	770	30	36	1	1	1
05PA012	64	1	750	22	37	1	1	1
05PB009	28	1	790	22	38	1	1	1
05PC018	11	1	750	22	39	4	2	1
05PC019	30	1	755	22	40	2	2	1
05PD026	12	1	740	22	41	1	1	1
05PE005	23	1	720	19	42	1	1	1
05PE011	33	1	720	19	43	1	1	1
05QA001	60	0	790	22	44	1	1	1
05QC001	29	1	720	22	45	1	1	1
05QD003	27	0	775	22	46	1	1	1
05QD006	28	1	770	22	47	1	1	1
05QD016	21	1	775	23	48	1	1	1
05QE006	49	1	700	20	49	2	2	1
05QE007	35	1	695	20	50	2	2	1
05QE008	21	0	750	19	51	1	1	1
05QE009	31	0	760	19	52	1	1	1

Page 80 SPSS/PC+ 7/13/93

Number of Clusters

Label					Case	4	3	2
02BF001	24	0	999	30	53	1	1	1

02BF002	24	0	895	30	54	1	1	1
02BF004	12	0	900	30	55	1	1	1
02BF006	12	0	895	30	56	1	1	1
02CA002	20	0	930	30	57	1	1	1
02CC007	41	1	890	29	58	1	1	1
02CC008	40	1	885	27	59	1	1	1
02CC009	31	1	885	28	60	1	1	1
02CC010	11	1	890	28	61	1	1	1
02CD001	25	0	900	25	62	1	1	1
02CD002	14	1	900	25	63	1	1	1
02CD004	22	1	900	25	64	1	1	1
02CD006	23	0	900	25	65	1	1	1
02CE001	44	1	890	25	66	1	1	1
02CE002	76	1	880	25	67	1	1	1
02CF007	31	0	795	25	68	1	1	1
02CF010	15	1	800	25	69	1	1	1
02CF012	14	0	800	26	70	1	1	1

Number of Clusters

Label					Case	4	3	2
02DB007	11	0	805	26	71	1	1	1
02DC003	70	1	830	27	72	1	1	1
02DC008	53	1	825	26	73	1	1	1
02DD005	47	1	830	27	74	1	1	1
02DD009	35	1	890	27	75	1	1	1
02DD010	30	1	850	27	76	1	1	1
02DD013	17	0	860	27	77	1	1	1
02DD016	11	1	870	27	78	1	1	1
02DD017	11	1	870	27	79	1	1	1
02EA005	76	0	930	29	80	1	1	1
02EA006	76	1	930	29	81	1	1	1
02EA010	23	0	920	28	82	1	1	1
02EA011	18	1	935	28	83	1	1	1
02EA013	11	0	940	28	84	1	1	1
02JC008	23	0	790	28	85	1	1	1
02JD010	19	1	830	28	86	1	1	1
02JE018	12	0	850	26	87	1	1	1
02JE019	19	1	850	26	88	1	1	1

Number of Clusters

Label					Case	4	3	2
02JE020	20	1	850	26	89	1	1	1
04KA001	21	0	720	22	90	1	1	1
04LA002	22	1	830	22	91	1	1	1
04LF001	73	1	820	30	92	1	1	1
04LG002	24	1	760	22	93	4	2	1
04LJ001	71	0	820	30	94	1	1	1
04LM001	19	0	780	25	95	2	2	1
04MD004	14	0	815	30	96	1	1	1
04ME002	59	1	760	30	97	2	2	1
04ME003	32	1	750	30	98	2	2	1
04MF001	25	0	720	22	99	1	1	1

```
Page 113                                  SPSS/PC+                                  7/13/93

 Dendrogram using Complete Linkage

                                           Rescaled Distance Cluster Combine

          C A S E                0         5        10        15        20        2
 Label                     Seq   éááááááááéáááááááááéáááááááááéáááááááááéáááááááá

 02DD016   11 1 870 27     78     á¢
 02DD017   11 1 870 27     79     áÇ
 02BF004   12 0 900 30     55     áÇ
 02EA013   11 0 940 28     84     áÇ
 02CD002   14 1 900 25     63     áÇ
 02DD013   17 0 860 27     77     áÇ
 02AB014   19 0 780 24      6     áÇ
 02AB016   14 1 780 23      8     áÇ
 02CF007   31 0 795 25     68     áÇ
 02JE018   12 0 850 26     87     áÇ
 02DD009   35 1 890 27     75     áÇ
 02EA005   76 0 930 29     80     áÇ
 02CA002   20 0 930 30     57     áÇ
 02EA010   23 0 920 28     82     áÇ
 02CD006   23 0 900 25     65     áÇ
```

```
Page 114                                  SPSS/PC+                                  7/13/93

          C A S E                0         5        10        15        20        2

 Label                     Seq   éááááááááéáááááááááéáááááááááéáááááááááéááááááááá

 02CF012   14 0 800 26     70     áÇ
 02BF006   12 0 895 30     56     áÇ
 02DB007   11 0 805 26     71     áÇ
 02AB011   67 1 780 23      5     áÇ
 02AD009   48 1 780 25     10     áÇ
 05PE005   23 1 720 19     42     áÇ
 05PE011   33 1 720 19     43     áÇ
 04CA004   19 0 590 19     20     áÇ
 02CD004   22 1 900 25     64     áÇ
 02EA006   76 1 930 29     81     áÇ
 02AB015   14 1 780 24      7     áÇ
 04MD004   14 0 815 30     96     áÇ
 02DD005   47 1 830 27     74     áÇ
 02JE020   20 1 850 26     89     áÇ
 02AD010   20 0 788 25     11     áÇ
 02AE001   17 0 805 24     12     áéá¢
 02AC001   20 0 785 24      9     áÇ °
 04CA003   24 0 590 20     19     áÇ °
```

```
Page 115                                  SPSS/PC+                                  7/13/93

          C A S E                0         5        10        15        20        2

 Label                     Seq   éááááááááéáááááááááéáááááááááéáááááááááéááááááááá

 05PD026   12 1 740 22     41     áÇ °
 02AB009   34 1 785 23      3     áÇ °
```

```
02EA011   18 1 935 28    83    áÇ °
04JC002   41 0 810 30    35    áÇ °
02DC008   53 1 825 26    73    áÇ °
05QD003   27 0 775 22    46    áÇ °
05QD016   21 1 775 23    48    áÇ °
02CD001   25 0 900 25    62    áÇ °
02CE002   76 1 880 25    67    áÇ °
02BF002   24 0 895 30    54    áÇ °
02JE019   19 1 850 26    88    áÇ °
02BA002   21 0 840 23    13    áÇ °
02CC010   11 1 890 28    61    áÇ °
02BF001   24 0 999 30    53    áÇ ûááááá¢
02BB002   24 0 875 24    14    áÇ °     °
02JC008   23 0 790 28    85    áÇ °     °
02AA001   68 0 800 23     1    áÇ °     °
02CF010   15 1 800 25    69    áÇ °     °
---------------------------------------------------------------------------
ge 116                               SPSS/PC+                       7/13/93

        C A S E                0         5         10        15        20        25
 Label                   Seq   éááááááááéááááááááéááááááááéááááááááéááááááááé

05QE009   31 0 760 19    52    áÇ °     °
04FA002   24 1 700 26    29    áÇ °     °
05QE008   21 0 750 19    51    áì °     °
04DC002   24 0 500 21    27    á¢ °     °
05QC001   29 1 720 22    45    áÇ °     °
04CD002   20 0 550 19    23    áÇ °     °
04CE002   23 0 600 23    24    áÇ °     °
04KA001   21 0 720 22    90    áÇ °     °
05PA012   64 1 750 22    37    áÇ °     °
02BB003   21 0 860 24    15    áÇ °     °
04JA002   37 0 810 30    34    áÇ °     °
02AB006   64 1 785 23     2    áéáì     ûááááááááááááááááááá¢
05QD006   28 1 770 22    47    áÇ       °                     °
02AB010   68 1 785 23     4    áÇ       °                     °
04LF001   73 1 820 30    92    áÇ       °                     °
02DC003   70 1 830 27    72    áÇ       °                     °
02JD010   19 1 830 28    86    áÇ       °                     °
04MF001   25 0 720 22    99    áÇ       °                     °
---------------------------------------------------------------------------
ge 117                               SPSS/PC+                       7/13/93

        C A S E                0         5         10        15        20        25
Label                    Seq   éááááááááéááááááááéááááááááéááááááááéááááááááé

02CC007   41 1 890 29    58    áÇ       °                     °
04DA001   25 0 650 24    25    áÇ       °                     °
05PB009   28 1 790 22    38    áÇ       °                     °
04GA002   23 0 720 23    16    áÇ       °                     °
04JF001   22 0 770 30    36    áÇ       °                     °
04LA002   22 1 830 22    91    áì       °                     °
05QA001   60 0 790 22    44    á¢       °                     ûáááááááááááááááá¢
02DD010   30 1 850 27    76    áéá¢     °                     °                 °
04GC002   16 1 735 26    32    áì °     °                     °                 °
04FA001   25 1 700 26    28    á¢ ûáááááì                     °                 °
04LJ001   71 0 820 30    94    áÇ °                           °                 °
02CC008   40 1 885 27    59    áÇ °                           °                 °
```

```
  02CC009  31 1 885 28   60   áéáì                                        °
  04GB004  20 0 740 26   17   áÇ                                          °
  02CE001  44 1 890 25   66   áÇ                                          °
  04CB001  24 0 590 20   21   áì                                          °
  04DC001  14 0 590 22   26   áôááá¢                                      °
  05PC018  11 1 750 22   39   áì    ûáááááááááááááá¢                      °
```

```
          C A S E              0         5         10         15         20

  Label                  Seq  éááááááááéááááááááéááááááááéááááááááéáááááááá

  04LG002  24 1 760 22   93   áááááì              °           °
  05QE006  49 1 700 20   49   áôá¢                °           °
  04ME003  32 1 750 30   98   áì ûáááááá¢         ûáááááááááááááì
  04LM001  19 0 780 25   95   á¢ °     °          °
  04ME002  59 1 760 30   97   áéáì     °          °
  04FB001  24 0 700 26   30   áì       ûáááááááááì
  04CA002  14 0 590 19   18   á¢       °
  04FC001  23 0 650 23   31   áÇ       °
  05QE007  35 1 695 20   50   áéá¢     °
  05PC019  30 1 755 22   40   áì ûááááááì
  04GD001  22 1 710 25   33   áááì
  04CC001  19 0 595 23   22   áááááááááááááááááááááááááááááááááááááááááááááá
```

This procedure was completed at 14:56:24

FINISH.

End of Include file.

APPENDIX E

REGIONAL INDEX LOW FLOW FREQUENCY DISTRIBUTION METHOD

APPENDIX E
REGIONAL INDEX LOW FLOW FREQUENCY DISTRIBUTION METHOD

The regional index frequency distribution method for predicting low flow characteristics is described below:

Suppose that data is available at N sites in a region, with sample size N_i at site i. Let $Q_i(F)$ be the quantile of probability F at site i. The key assumption of an index drought procedure is that the region is homogeneous, that is the frequency distributions of the N sites are identical apart from a site-specific scaling factor, the index drought. It may then be written:

$$Q_i(F) = Q_{index}\, q(F) \qquad i = 1,...N \tag{E - 1}$$

Where Q_{index} is the index low flow. For the purposes of this study, Q_{index} is taken to be the $7Q_2$ of the at-site frequency distribution, though any location parameter of the frequency distribution may be used instead. Determination of the remaining factor in (E-1), q(F), 0<F<1, identifies the "regional frequency curve", which defines a dimensionless regional frequency distribution common to all sites.

The dimensionless rescaled data $q_{ij} = Q_{ij}/Q_{index}$, $j = 1,...N_i$, $i = 1,...,N$, are the basis for estimating q(F). In this study, the parameters are estimated separately at each site. The site i estimate of parameter Q_k is denoted by $\hat{Q}_k^{(i)}$. The at-site estimates are combined to give regional estimates:

$$\hat{Q}_k^{(R)} = \sum_{i=1}^{N} N_i\, \hat{Q}_k^{(i)} \,/\, \sum_{i=1}^{N} N_i \tag{E - 2}$$

This is a weighted average, with the site i estimate given weight proportional to N_i since for regular statistical models the variance of $\hat{Q}_k^{(i)}$ is inversely proportional to N_i. Substituting these estimates into q(F) gives the estimated regional quantiles q(F).

The site i quantile estimates are obtained by combining the estimates of $7Q_{2i}$ and $\hat{q}(F)$.

$$\hat{Q}_i(F) = 7Q_{2i}\, \hat{q}(F) \tag{E - 3}$$

To use this method, the following steps can be followed:

1. Estimate $7Q_{2i}$ for ungauged site i by using isolines, the regression method graphical analysis for the region or short term measurements which may be available for the site.

2. If another low flow characteristic is required, $7Q_{20i}$ for example, then find the regional frequency curve parameters, that is regional a, e, and u for the Weibull III distribution based on the location of the site (see Table 4.1).

3. Using the regional parameters to estimate the quantile of dimensionless low flow, $\hat{q}_y$, where y is the occurrence interval.

$$\hat{q}_y = e + (u - e) \{ - \ln [1 - \frac{1}{y}] \}^{\frac{1}{a}} \tag{E - 4}$$

where a, e, and u are obtained from Table 4.1.

4. The final step is to transfer the low flow quantile $\hat{q}_y$ to the site:

$$Q_y = 7Q_2 \, \hat{q}_y \tag{E - 5}$$

As example application of this technique for station #02DD015 (one of the stations reserved for testing) is described as follows:

1. Find the low flow index ($7Q_2$) based on the isoline method. The estimation is $7Q_2 = 0.106$ m^3/s for 02DD015.

2. Find the regional Weibull III distribution parameters. Station 02DD015 belongs to Sub-Region Three, and thus the a, e, and u values for 7 day low flows of the sub-regions should be 1.580, 0.221 and 1.203 respectively (see Table 4.1).

3. Compute the regional 20 years low flow quantile

$$\hat{q}_{20} = 0.221 + (1.203 - 0.221) \{ - \ln [1 - \frac{1}{20}] \}^{\frac{1}{1.580}} = 0.37086$$

4. Calculate the $7Q_{20}$ for 02DD015 as:

$7Q_{20}$ = 0.37086*0.106 m^3/s

= 0.0393 m^3/s

The recorded $7Q_{20}$ for 02DD015 is 0.04 m^3/s which compared well with the estimated $7Q_{20}$ of 0.0393 m^3/s.

APPENDIX F

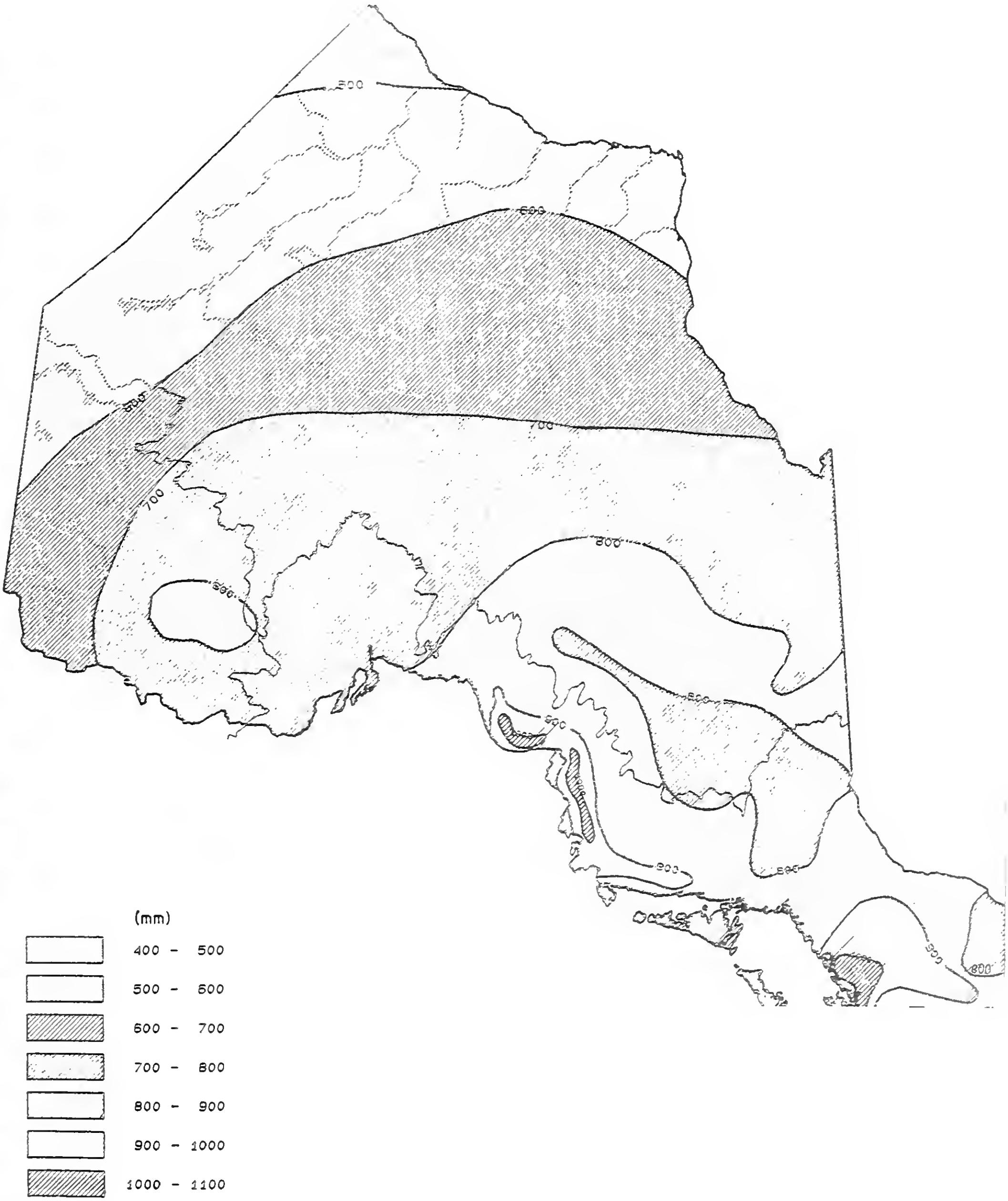
METEOROLOGIC AND PHYSIOGRAPHIC DATA

APPENDIX F
METEOROLOGIC AND PHYSIOGRAPHIC DATA

Meteorologic and Physiographic Data

The maps showing physiographic and meteorologic information used in this study, such as MAP, MAS, MAR and EVA etc, are presented in Appendix F. Other related information which was useful in helping to identify the sub-regions is also summarized, including; annual groundwater contribution to local streamflow, groundwater yields from bedrock, bedrock geology and surficial geology.

Figure F.1	Title:	Mean Annual Precipitation
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.2	Title:	Mean Annual Snowfall
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.3	Title:	Mean Annual Runoff
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.4	Title:	Mean Annual Evapotranspiration
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.5	Title:	Annual Groundwater Contribution to Local Streamflow
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.6	Title:	Groundwater Yields From Bedrock
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.7	Title:	Bedrock Geology
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984
Figure F.8	Title:	Surficial Geology
	Source:	Water Quality Resource of Ontario, Ministry of Natural Resources, 1984

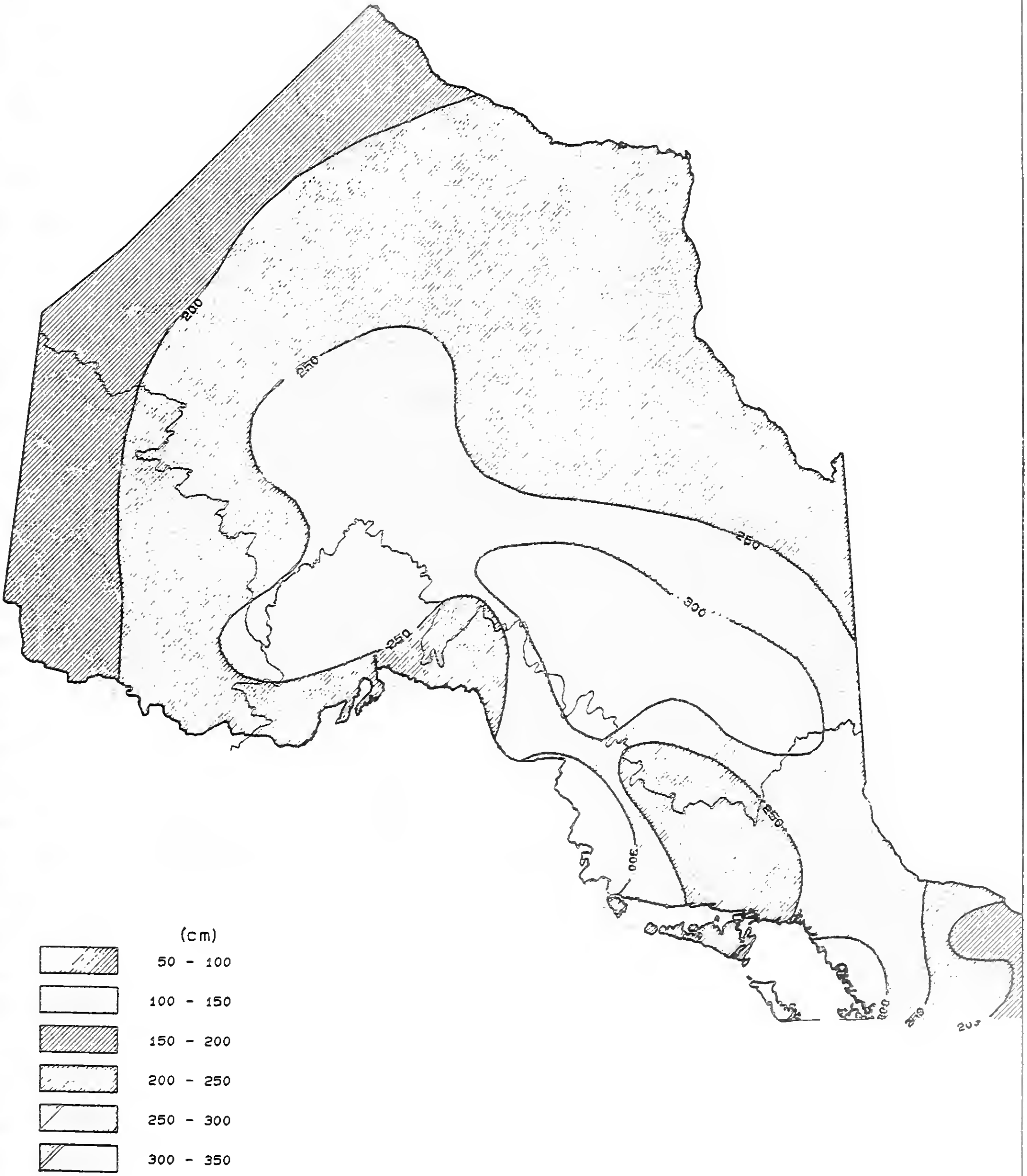


Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

MEAN ANNUAL PRECIPITATION

FIGURE F.1

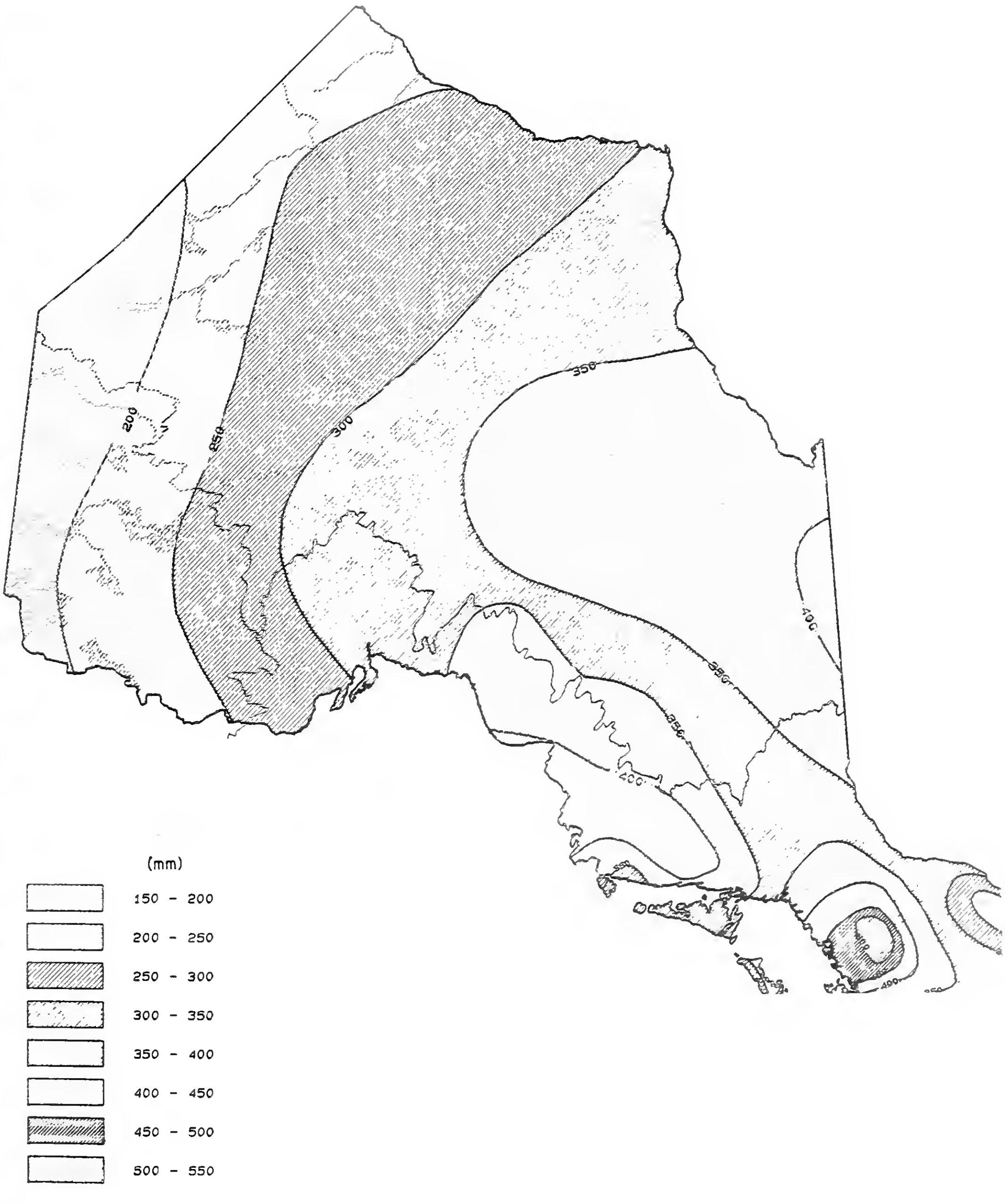


Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

MEAN ANNUAL SNOWFALL

FIGURE F.2

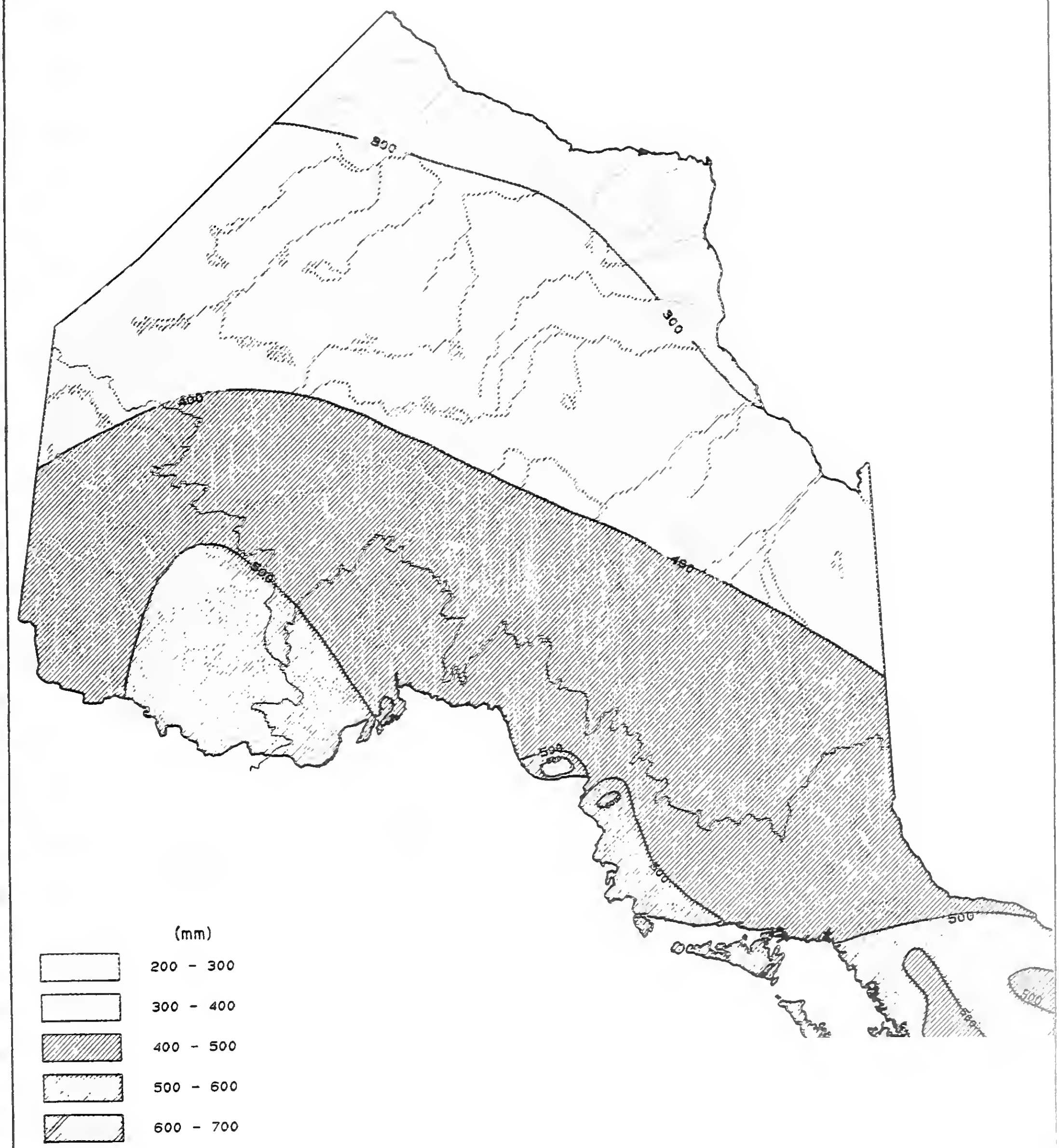


Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

MEAN ANNUAL RUNOFF

FIGURE F 3

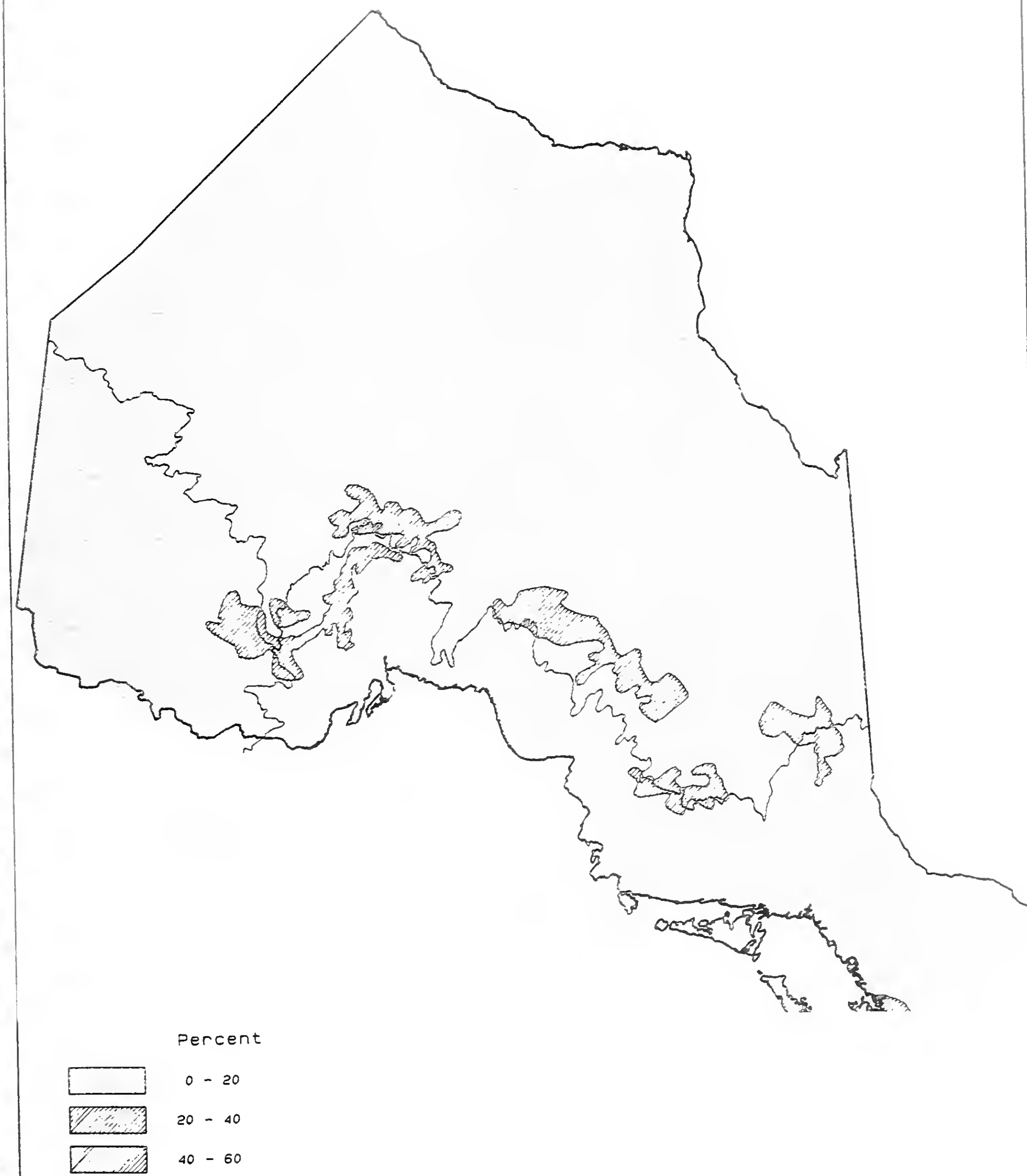


Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

MEAN ANNUAL EVAPOTRANSPIRATION

FIGURE F 4

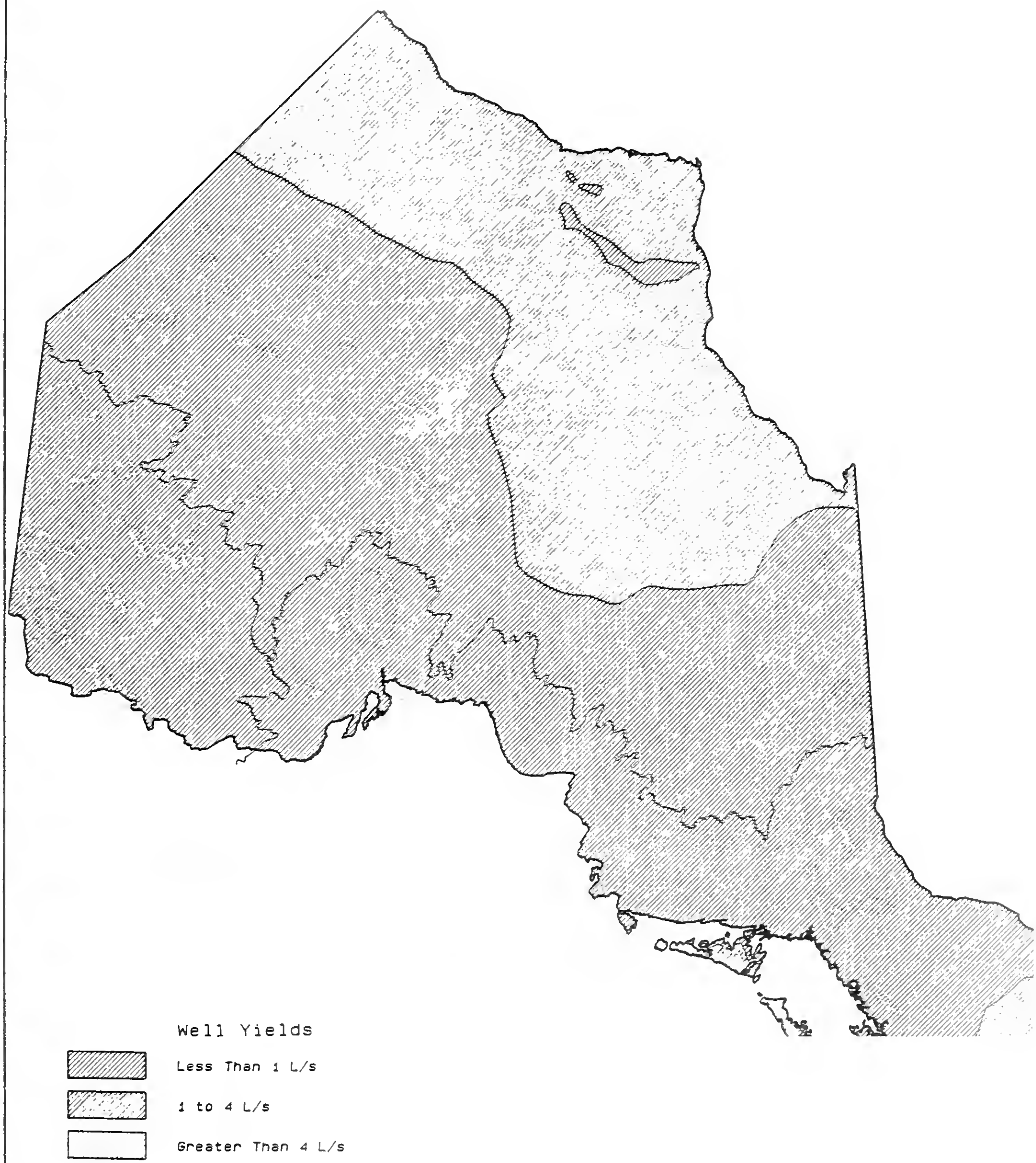


Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

ANNUAL GROUNDWATER CONTRIBUTION TO LOCAL STREAMFLOW

FIGURE F.5

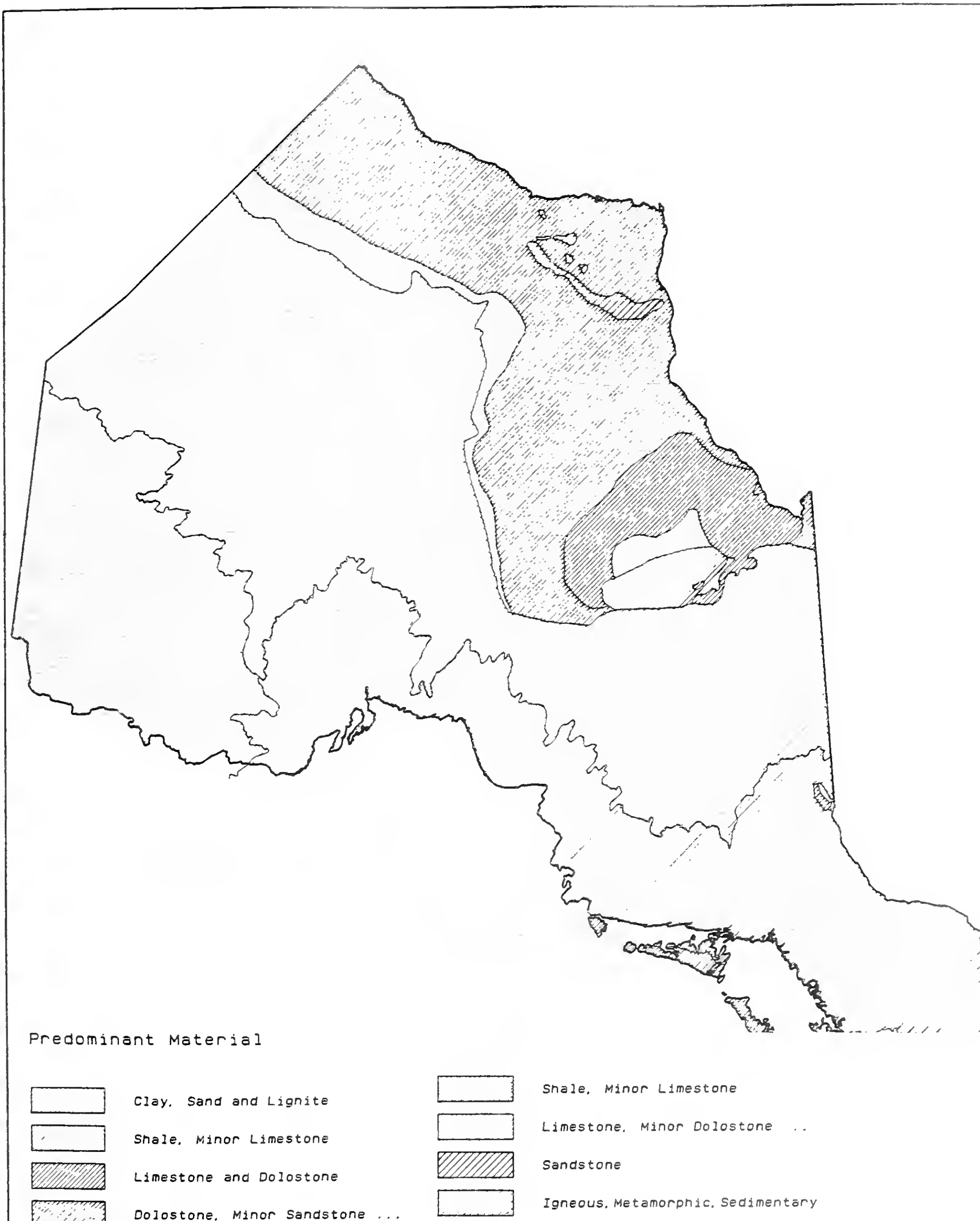


Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

GROUNDWATER YIELDS FROM BEDROCK

FIGURE F 6

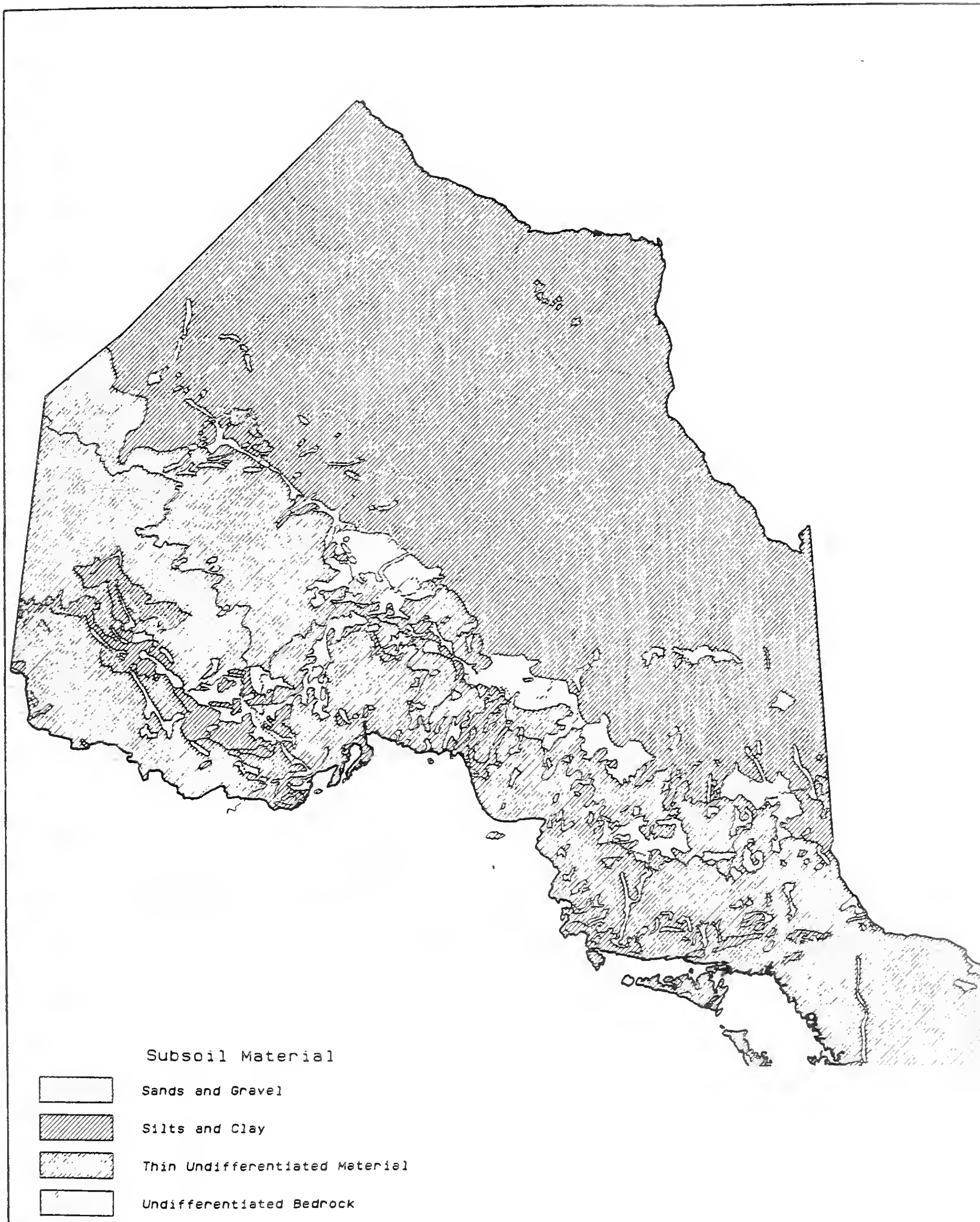


Cumming Cockburn
Consulting Engineers, Planners and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

BEDROCK GEOLOGY

FIGURE F.7



Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

SURFICIAL GEOLOGY

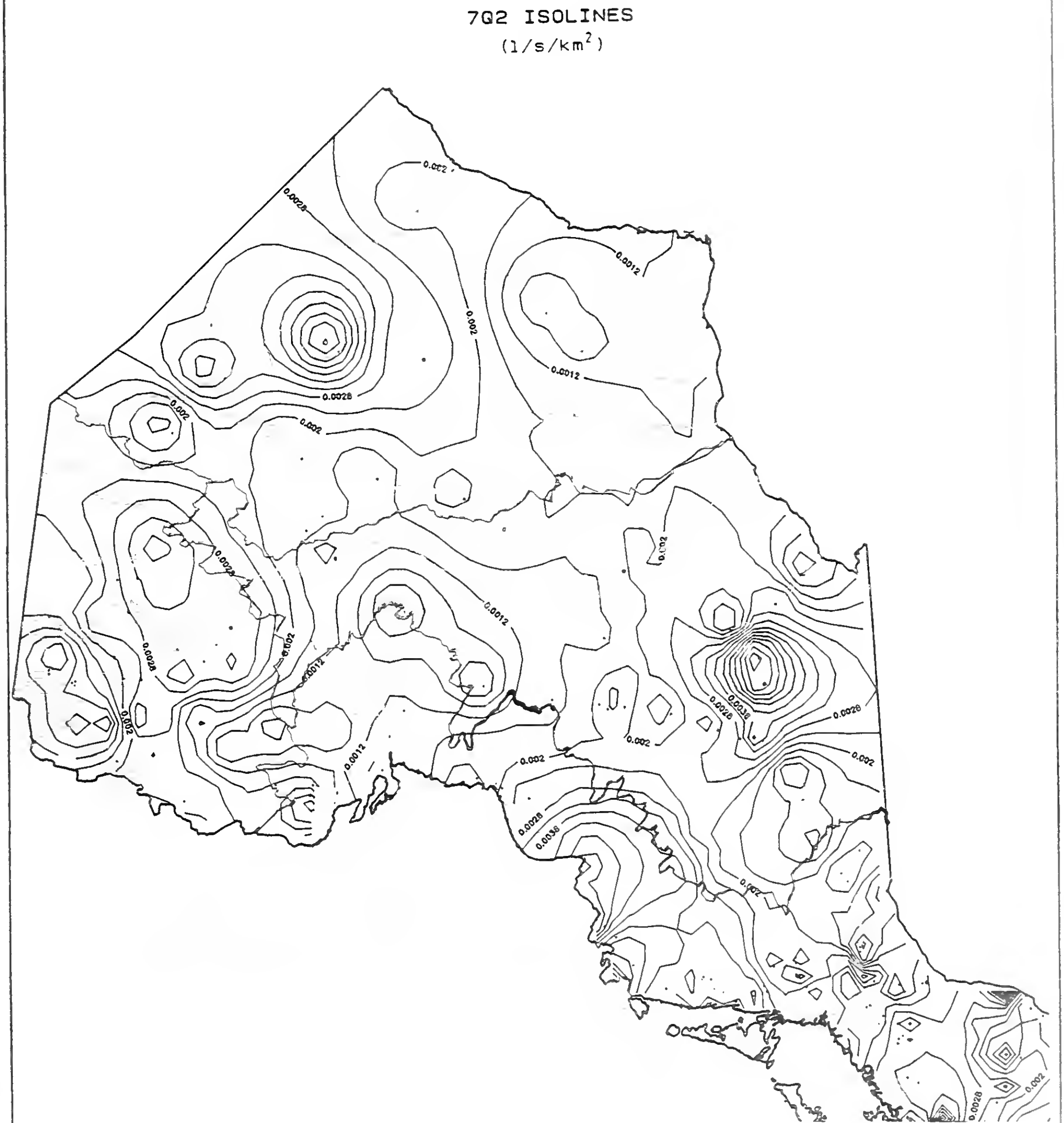
FIGURE F 8

APPENDIX G
COMPUTER GENERATED ISOLINES

APPENDIX G
COMPUTER GENERATED ISOLINES

__Computer Generated Isolines__

Figure G.1 and G.2 show the computer generated isolines of $7Q_2$ and $7Q_{20}$. These were used as a starting point for generating the manually drawn isolines (see Figures 4.1 and 4.2) taking into account station density and hydrologic experience and judgement.



Cumming Cockburn
Consulting Engineers, Planners
and Environmental Scientists

REGIONALIZATION OF LOW FLOW CHARACTERISTICS NORTHEASTERN AND NORTHWESTERN ONTARIO

$7Q_2$ ISOLINES
(COMPUTER GENERATED)

FIGURE G 1

6 736	137 0
5 234	18 70
4 393	10 50
3 684	6 700
1 810	4 380
51-86	3290
04JC003N	

170 0
33 50
19 10
9 370
1 840
4170
004R

LOW FLOW CHARACTERISTICS OF STREAMS IN NORTHWESTERN ONTARIO

Cumming Cockburn Limited
Consulting Engineers and Planners

Consulting Engineers and Planners

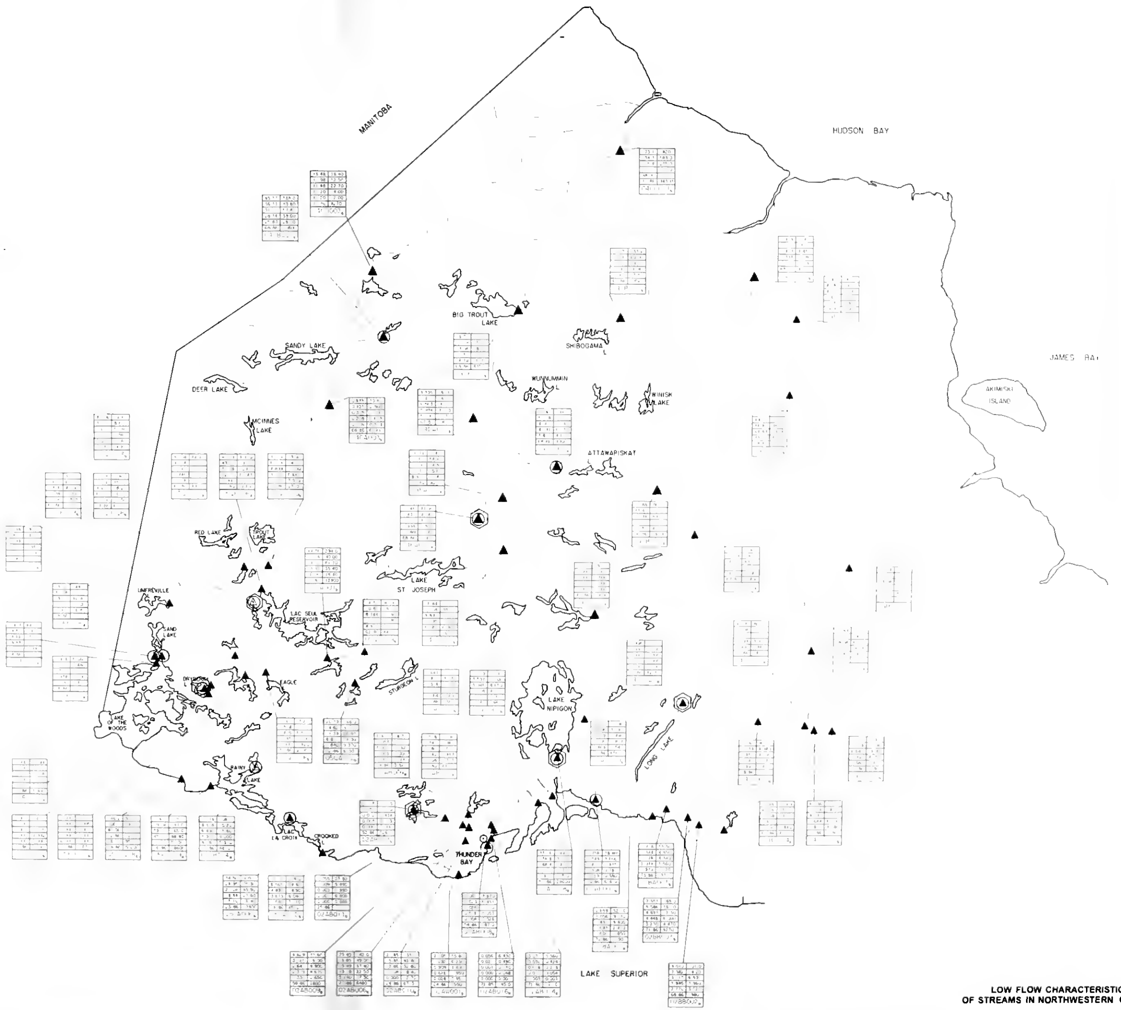
ARIO

50	39.10
91	7.990
161	4.960
153	2.440
520	0.906
-83	787.0
2DD005R	

52 40
12 00
7.010
3 340
2.370
1130
019R

LOW-FLOW CHARACTERISTICS OF STREAMS IN NORTHWESTERN ONTARIO

Ministry of the Environment
Water Resources Branch



TREND SIGNIFICANT DOWNWARD

TREND SIGNIFICANT UPWARD

LOW FLOW CHARACTERISTICS OF STREAMS IN NORTHWESTERN ONTARIO

Cumming Cockburn Limited
Consulting Engineers and Planners

	52.40
	12.00
	7.010
	3 340
	2.370
	1130

E019R

150	39.10
291	7.990
.961	4 960
.753	2.440
520	0.906
7-83	787.0

2DD005R

TARIO

Cumming Cockburn Limited

Consulting Engineers and Planners

UNIT

LOW-FLOW CHARACTERISTICS OF STREA

IN

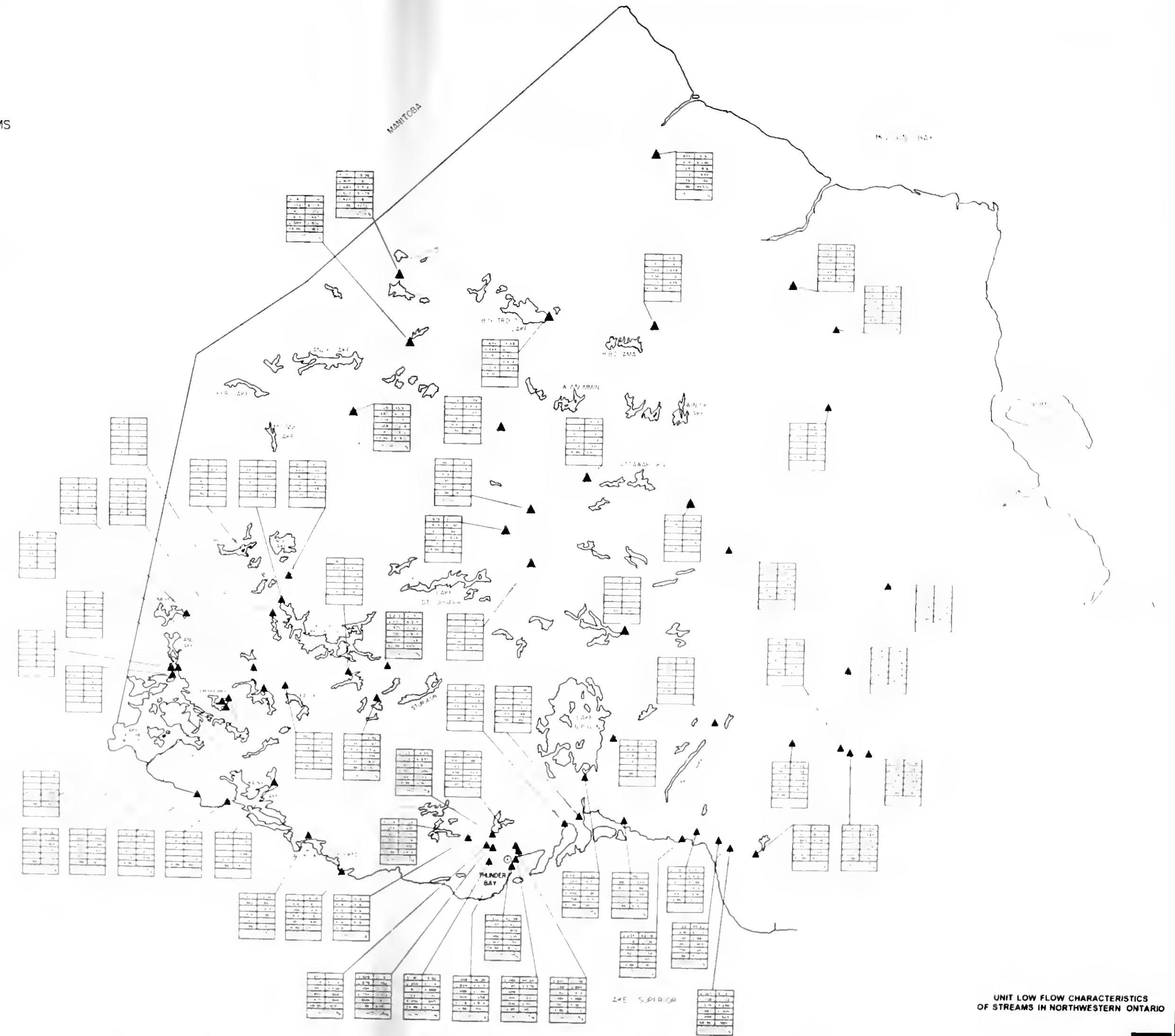
NORTHWESTERN ONTARIO

Ministry of the Environment

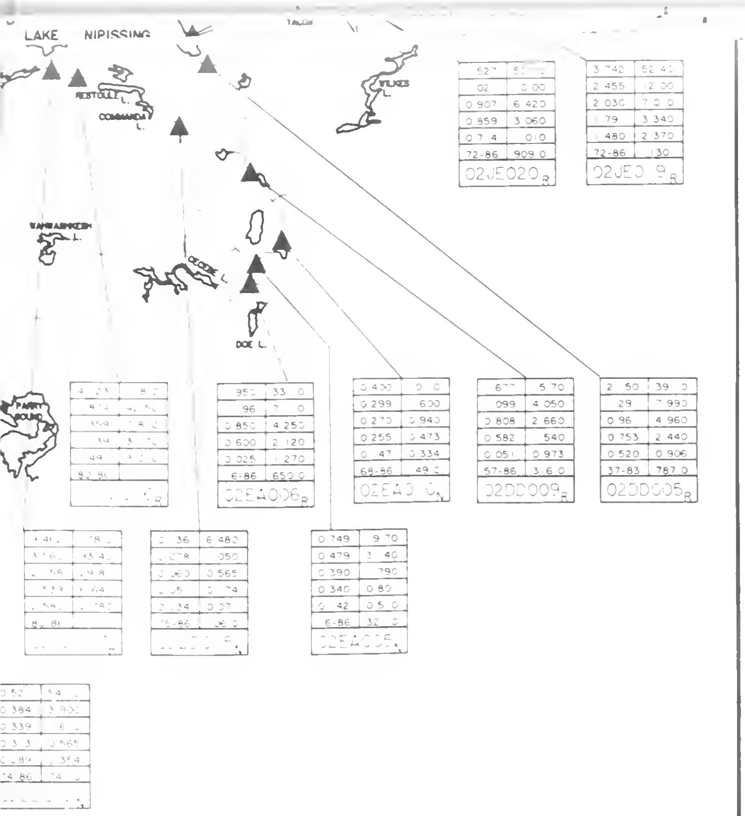
Water Resources Branch

UNIT
LOW-FLOW CHARACTERISTICS OF STREAMS IN NORTHWESTERN ONTARIO

Ministry of the Environment
Water Resources Branch



UNIT LOW FLOW CHARACTERISTICS
OF STREAMS IN NORTHWESTERN ONTARIO

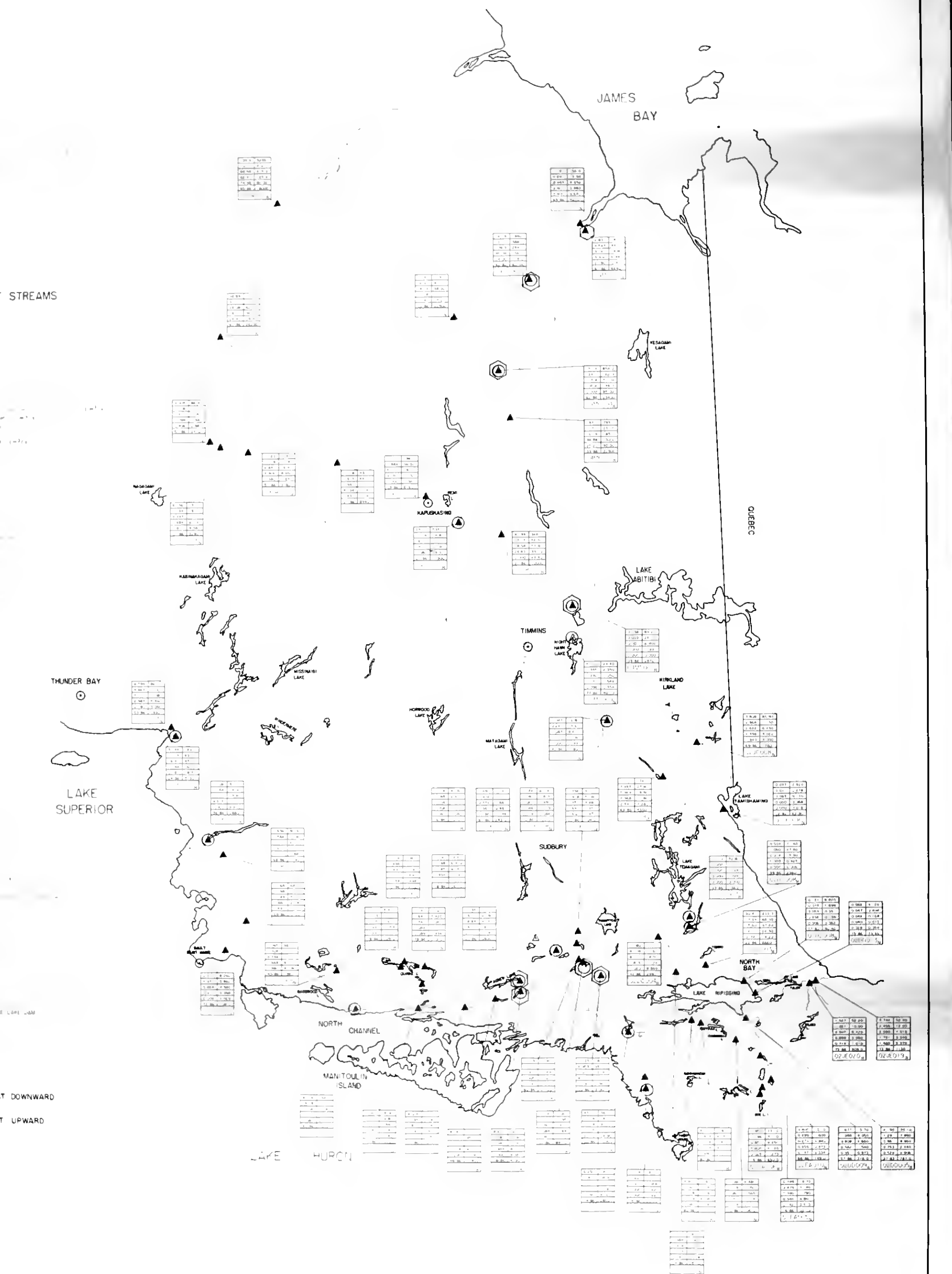


LOW FLOW CHARACTERISTICS OF STREAMS IN NORTHEASTERN ONTARIO

Cumming Cockburn Limited
Consulting Engineers and Planners

LOW-FLOW CHARACTERISTICS OF STREAMS IN NORTHEASTERN ONTARIO

Ministry of the Environment
Water Resources Branch

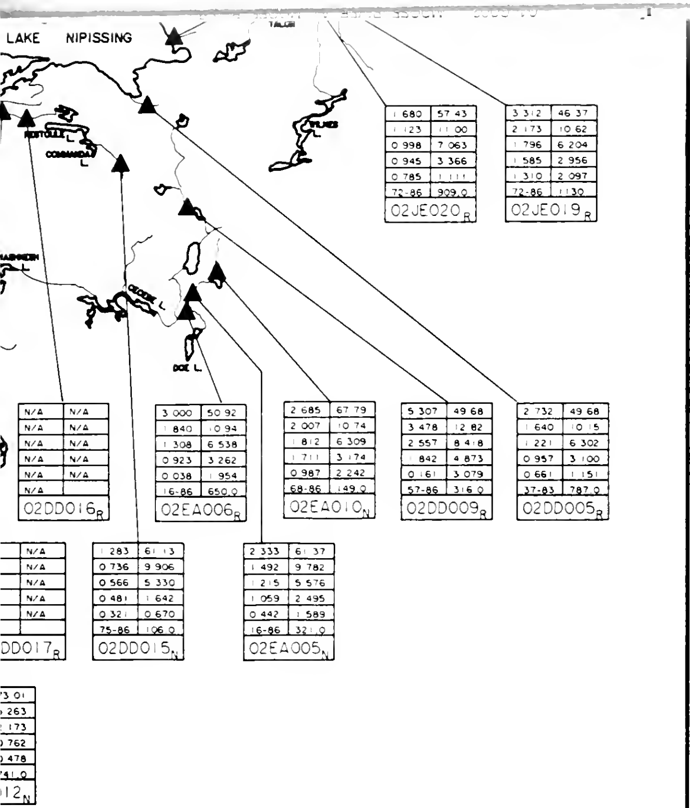


04LD001 GROUNDHOG RIVER AT FAUQUIER
04LF001 KAPUSKASING RIVER AT KAPUSKASING
04LG002 MOOSE RIVER AT MOOSE RIVER
04LJ001 MISSINAIBI RIVER AT MATTICE
04LM001 MISSINAIBI RIVER BELOW BABOOSE RIVER
04MB002 FREDERICK HOUSE RIVER AT FREDERICK HOUSE LAKE DAM
04MD004 PORCUPINE RIVER AT HOYLE
04ME003 ABITIBI RIVER AT ABITIBI CANYON
04ME004 ABITIBI RIVER AT OTTER RAPIDS
02CE002 AUX SABLES RIVER AT MASSEY

TREND SIGNIFICANT DOWNWARD

TREND SIGNIFICANT UPWARD

LOW FLOW CHARACTERISTICS OF STREAMS IN NORTHEASTERN ONTARIO

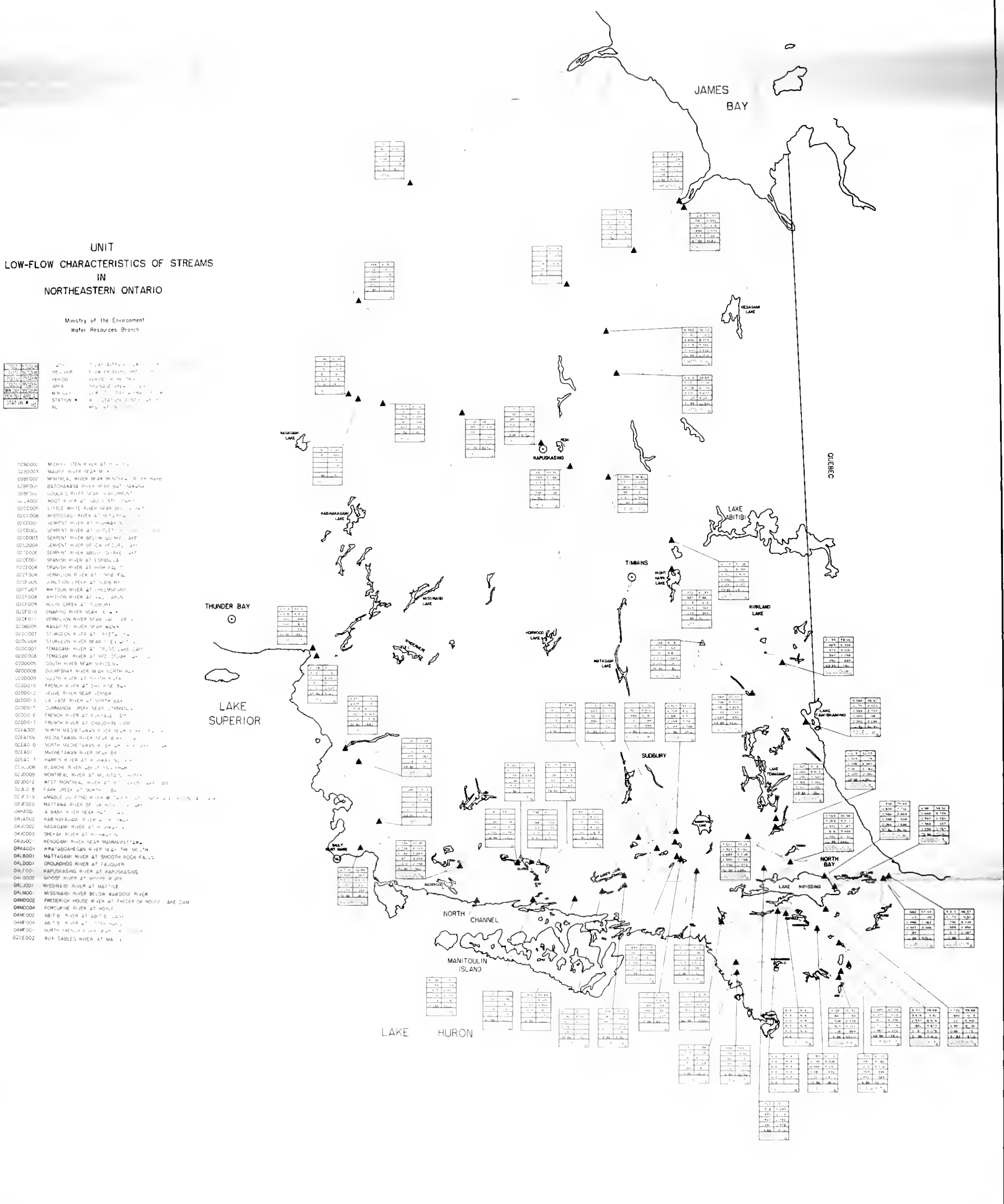


UNIT LOW FLOW CHARACTERISTICS OF STREAMS IN NORTHEASTERN ONTARIO

Cumming Cockburn Limited
Consulting Engineers and Planners

UNIT
LOW-FLOW CHARACTERISTICS OF STREAMS
IN
NORTHEASTERN ONTARIO

Ministry of the Environment
Water Resources Branch



UNIT LOW FLOW CHARACTERISTICS
OF STREAMS IN NORTHEASTERN ONTARIO